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RADIO CHANNEL CHARACTERISTICS IN HIGH-SPEED TRAIN WIRELESS COMMUNICATION CUTTING SCENARIO

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ABSTRACT

Cutting scenario is one of the common and major scenarios in HST wireless communication, as it is used for flatness and smoothness of HST track. However, very few research has been carried out on how cutting shape affects the wireless communication system in HST, hence the reasons for embarking on the investigation of radio channel characteristics in HST wireless communication in the cutting scenario. In this paper, four key parameters were identified in the cutting scenario; the width-up (W_{up}), width-down(W_{down}), the slope of cuttings and vegetation of the environment. The statistical properties of the channel model determined, the two correlation functions; Cross correlation function and Autocorrelation function determined from the simulation. The result shows that there is a higher correlation with the larger sum of W_{up} and W_{down}. Also, there is a similarity between the theoretical and simulated channel model.

Keywords: Autocorrelation function, Channel model, Cross correlation function, Cutting scenario, High speed train, Wireless communication

INTRODUCTION

With the advance in technology, High-speed train (HST) has become one of the latest means of transportation that people prefer due to its safety, comfort, reliability, conveniences, high efficiency, economic, environmental friendliness, and time savings. HST maximum speed of about 575 km/h has been achieved by French National rail corporation (Cheng-Xiang *et al.,* 2016*)*. In respect to this, the wireless communication system has a vital role to play in passenger's mobile communication, train control and signaling system, monitoring, security, and maintenance of rail transportation system.

However, HST wireless communication system is faced with a lot of challenges beyond the normal trains due to its speed and topographical differences in its terrestrial environment as it travels along. Many kinds of literature classified HST geographical environment into different scenarios such as open space, Hilly terrain, station, tunnel, viaduct and cuttings. A lot of investigation has been done separately on radio channel characteristics for each of these scenarios, but very little was said in the cutting scenario which is one of the main terrains in HST rail track according to He *et al* (2012).

The introduction of HST has brought significant enhancement to rail transportation industry. To sustain the great demand of broadband service for data transfer, security and communications of the passenger pose a lot of challenge to its wireless communication systems. In designing HST wireless system accurate and efficient channel models for both large and small-scale fading characteristics are very important for its parameter optimisation and performance evaluation (Cheng-Xiang *et al.,* 2016).

The fifth generation (5G) communication system is expected to be dedicated for HST due to its high demand for network capacity for its passenger communication and operational control irrespective of its speed and its geographical location. Apart from regular communication challenge faced by conventional train, HST has other problems such as high Doppler spread, fast handovers, high speed through different geographical location, with the harsh electromagnetic environment, great penetration losses, and tunnel limited invincibility. All these challenges have been overcome or reduce to minimal for maximum optimisation of HST (Ghazal *et al.*, 2015).

HST communication system, as presented by Cheng-Xiang *et al.* (2016), faces a lot of different channel condition due to several geographical environments. These environments sometimes refer to as scenarios can be divided in to six categories viz: Station, tunnels, Hilly terrain, via duct, open space and cuttings. It is possible for HST to operate across two or more of these scenarios when it travels. These scenarios and the distance between the transmitter and receiver has great effect on propagation characteristics of HST wireless communication.

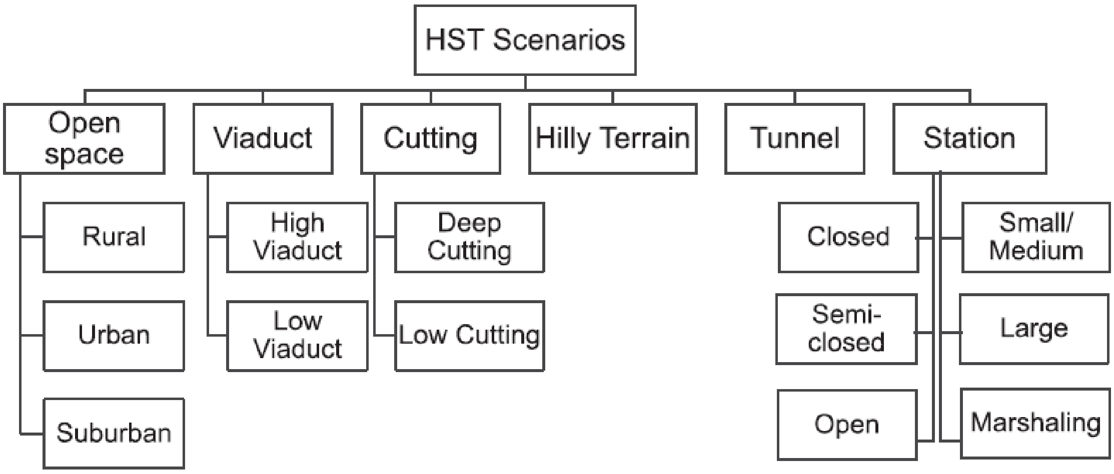


Figure 1: Classification of HST scenario. (Cheng-Xiang *et al.,* (2016),

Therefore, it is imperative to examine the impact of cutting scenario on radio channel characteristics of HST wireless communication system.

METHODOLOGY

To properly investigate the impact of cutting scenario on radio channel characteristics of HST wireless communication system. The following methods were applied; measurement results from the literature, channel modelling, and the statistical properties of the model channel were analysed. The key parameters of cutting scenario was also investigated, and MATLAB was used in the programming and finally test and simulation was carried out.

HST Channel Model in Cutting Scenario

The figure below show the structural front view of cutting scenario, the two steep walls by the sides will had a great effect on HST communication system, the height of Bs antennal led to a dominant LoS components in MRS sides. The richness of scatterers at the side walls was increased the tendency of multipath components which in turn led to a severe fading. The impact of cutting parameters: width up (W_{up}) and width down (W_{down}), the distance between the BS and MRS were represented by the Ricean K-factor, the relative height between BS and MRS was calculated as $h = Hcut + H_{BS} – (H_{train} + H_{MRS})$.

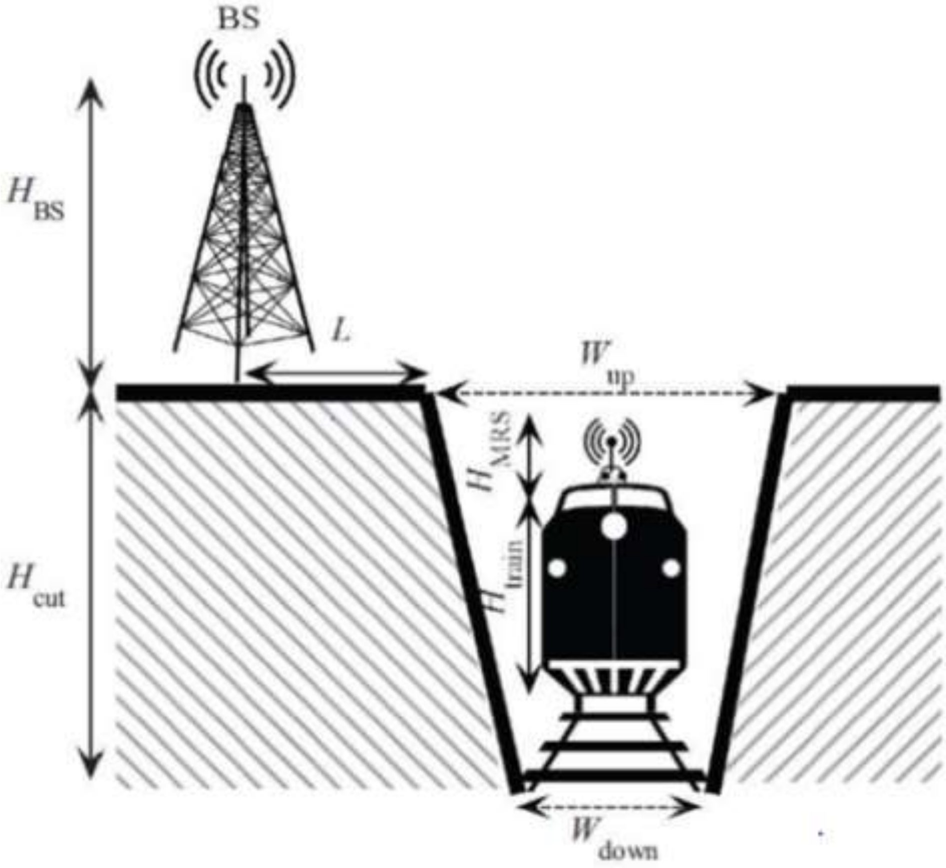


Figure 2: Cutting Scenario (*Ghazal et al., 2015)*

HST Channel Model Characterisation in Cutting Scenario

In the derivation of statistical properties for non- stationary HST GBSM; uncorrelated, scattered and stationary antenna was assumed (Ghazal et al., 2015), (Liu et al., 2016).

Time-Variant Space CCF: The properties of wideband MIMO HST channel is represented by the correlation of properties of two arbitrary channel impulse responses $\check{h}_{i,pq}(t) and\ \check{h}_{i,p'q'}(t)$ at different time intervals. Therefore, Time-variant space-time correlation function can be derived as follows:

$$\begin{aligned}\tilde{R}_h\left(t, \Delta x_T, \Delta x_R, \Delta t\right) &= \frac{E\left\{\tilde{h}_{i,pq}(t)\tilde{h}_{i,p'q'}(t-\Delta t)\right\}}{\sqrt{\Omega_{i,pq}\Omega_{i,p'q'}}} \\ &= \tilde{R}_h^{LOS}\left(t, \Delta x_T, \Delta x_R, \Delta t\right) + \tilde{R}_h^{SB_i}\left(t, \Delta x_T, \Delta x_R, \Delta t\right)\end{aligned} \quad 1$$

The time- variant space CCF between the two arbitrary channel impulse responses can be express when $\Delta t = 0$
Therefore,

$$\begin{aligned}\tilde{\rho}\left(t, \Delta x_T, \Delta x_R\right) &= \frac{E\left\{\tilde{h}_{i,pq}(t)\,\tilde{h}^*_{i,p'q'}(t)\right\}}{\sqrt{\Omega_{i,pq}\Omega_{i,p'q'}}} \\ &= \tilde{R}_h\left(t, \Delta x_T, \Delta x_R, 0\right)\end{aligned} \quad 2$$

Time- variant Autocorrelation function (ACF)

When equating $\Delta xT = 0$ and $\Delta xR = 0$, the time-variant ACF can be expressed as

$$\tilde{r}(t, \Delta t) = \frac{E\left\{\tilde{h}_{i,pq}(t)\,\tilde{h}^*_{i,pq}(t-\Delta t)\right\}}{\sqrt{\Omega_{i,pq}\Omega_{i,p'q'}}} = \tilde{R}_h(t, 0, 0, \Delta t) \quad 3$$

The above equation can be used to calculate the delay spread of propagation channel. The time variant CCF and ACF can be used to determine the impact of LoS component and the distribution of scatterers in HST cutting scenario since they are reflected to Ricean K-factor, $K_{pq}(t)$.

Where E {.} represent statistical operator and (.)* represent the complex conjugate operation.

The LoS component is given as

$$r^{\mathrm{LoS}}(t, \Delta t) = \frac{K_{pq}(t)}{1 + K_{pq}(t)}\, e^{j2\pi f_{\max}\cos\left(\phi^{\mathrm{LoS}}(t-\Delta t) - \gamma_R\right)\Delta t} \quad 4$$

While SB component is given as

$$\begin{aligned}r^{\mathrm{SB}_i}(t, \Delta t) = \frac{1}{N_i\left(1 + K_{pq}(t)\right)} \sum_{n_i=1}^{N_i} e^{j2\pi\xi_{TR}^{(n_i)}(t,\Delta t)} \\ \times e^{j2\pi f_{\max}\cos\left(\phi_R^{(n_i)} - \gamma_R\right)\Delta t}\end{aligned} \quad 5$$

Time -variant level crossing Rate (LCR)

This is defined as the average number of times per second that the signal envelope, $[h_{pq}(t)]$, crosses a specified level r with the positive and negative slope. Using the traditional PDF-based method.

LCR for HST channel is given as

$$\begin{aligned}L(t, r) &= \frac{2r\sqrt{K_{pq}(t) + 1}}{\pi^{3/2}} B(t)\, e^{-K_{pq}(t) - (K_{pq}(t)+1)r^2} \\ &\times \int_0^{\pi/2} \cosh\left(2\sqrt{K_{pq}(t)\left(K_{pq}(t) + 1\right)} \cdot r\cos\theta\right) \\ &\times \left[e^{-(\chi(t)\sin\theta)^2} + \sqrt{\pi}\chi(t)\sin\theta \cdot \mathrm{erf}(\chi(t)\sin\theta)\right] d\theta,\end{aligned} \quad 6$$

Where cosh (.) is the hyperbolic cosine function, *erf (.)* is the error function,

$$B(t) = \sqrt{\frac{b_2(t)}{b_0(t)} - \frac{b_1^2(t)}{b_0^2(t)}} \quad 7$$

$$x(t) = \sqrt{\frac{K_{pq}(t) b_1^2(t)}{\left(b_0(t) b_2(t) - b_1^2(t)\right)}} \quad 8$$

The parameters $b_0(t)$, $b_1(t)$and $b_2(t)$ are define as

$$b_0(t) = \frac{1}{K_{pq}(t) + 1}, \quad 9$$

$$b_1(t) = \frac{b_0(t)}{N_i} \sum_{n_i=1}^{N_i} f_{\max} \cos(\phi_R^{(n_i)} - \gamma_R), \qquad 10$$

$$b_2(t) = \frac{b_0(t)}{N_i} \sum_{n_i=1}^{N_i} \left[f_{\max} \cos(\phi_R^{(n_i)} - \gamma_R) \right]^2. \qquad 11$$

Stationary interval and stationary Distance:

From equation 10, the stationary interval can be expressed using average power delay profiles (APDPs) as Ghazal et al., 2015).

$$\overline{P_h}(t_k,\tau) = \frac{1}{N_{PDP}} \sum_{k}^{k+N_{PDP}-1} |h_{pq}(t_k,\tau)|^2 \qquad 12$$

Where N_{PDP} is the number of power delay profiles to be averaged, t_k is the time of the k-th drop and

$h_{pq}(t_{k,\tau}) = \sum_{i=1}^{I} h_{i,pq}(t_k)\delta(\tau - \tau_i)$.

The correlation coefficient between two APDPs can be calculated as

$$c(t_k,\Delta t) = \frac{\int \overline{P_h}(t_k,\tau)\,\overline{P_h}(t_k+\Delta t,\tau)\,\mathrm{d}\tau}{\max\{\int \overline{P_h}(t_k,\tau)^2\,\mathrm{d}\tau, \int \overline{P_h}(t_k+\Delta t,\tau)^2\,\mathrm{d}\tau\}}. \qquad 13$$

The stationary interval can be calculated as

$$T_s(t_k) = \max\{\Delta t|_{c(t_k,\Delta t)\geq c_{\text{thresh}}}\}, \qquad 14$$

C_{thresh} is the threshold of the correlation coefficient.

The stationary distance can also be calculated as

$$SD(t_k) = \max\{\Delta D|_{c(t_k,\Delta t)\geq c_{\text{thresh}}}\}, \qquad 15$$

Where $\Delta D = vR \; x \; \Delta t$.

Time-variant SD PSD:

This aspect of channel characteristics worth considering, it shows the PSD distribution along the Doppler frequency of the signals.this can be express by applying the Fourier transformation on time – variant ST CF regarding t (He et al., 2013). It is given as

$$W(t,\nu,\Delta x_T,\Delta x_R) = \int \tilde{R}_h(t,\Delta x_T,\Delta x_R,\Delta t) e^{-j2\pi\nu\Delta t} d\Delta t \qquad 16$$

RESULTS AND DISCUSSION:

Table I, gives the values of the result obtained from the simulation of HST channel model in cutting scenario. Four cutting width dimension were consider (Wup= 45, 50, 55 and 60) while (Wdown=14, 16, 18 and 20). It was observed that there is higher correlation as the width of cutting (Wup+Wdown) increases This was based on differences in there dimension, since cutting 4 is wider than cutting 1,2,and 3, therefore it has higher correlation than 1,2,3 as it can be seen in figure 21 and figure 22. There is an higher LOS components in cutting 4 as represented by a higher K-factor value. these also leads to higher ACF values.

Table 1: Cutting parameters theoretical values

S/N	Cutting Parameters	Values (m)			
		1	2	3	4
1	H_{CUT}	10	10	10	10
2	H_{BS}	30	30	30	30
3	H_{MRS}	0.3	0.3	0.3	0.3
4	H_{TRAIN}	3.8	3.8	3.8	3.8
5	L	10	10	10	10
6	W_{UP}	45	50	55	60
7	W_{DOWN}	14	16	18	20
8	Wup +Wdown	59	66	73	80
9	SLOPE	18	20	21	22
10	K-factor	18.7	24.5	30.3	36
11	Fc	930MHz			
12	vR	360Km/h			
13	D_{BP}	400m			

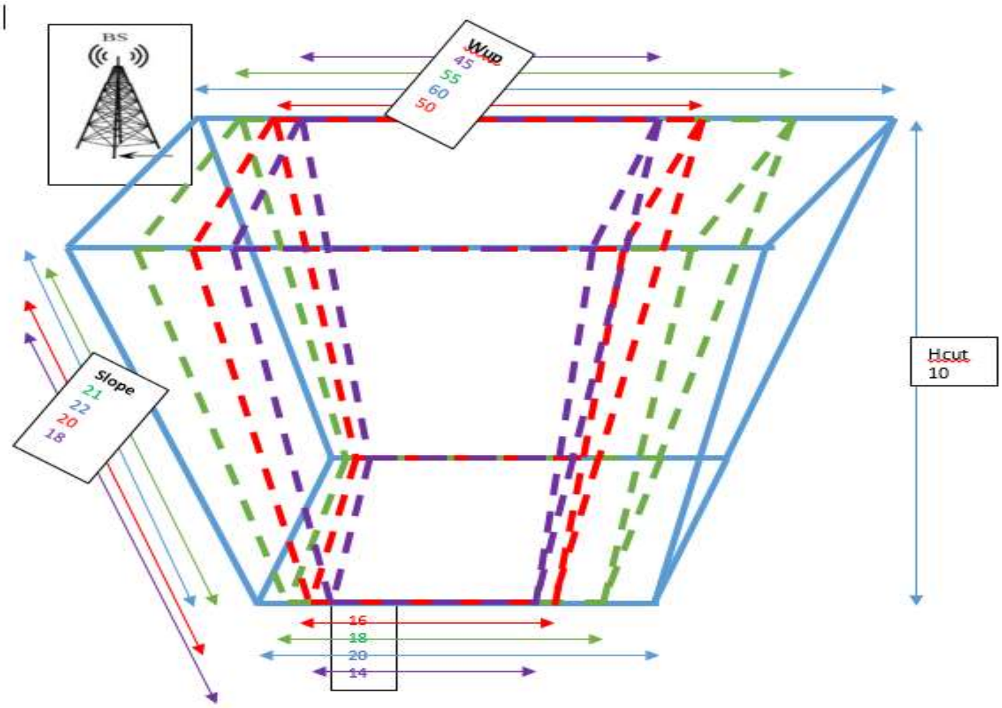
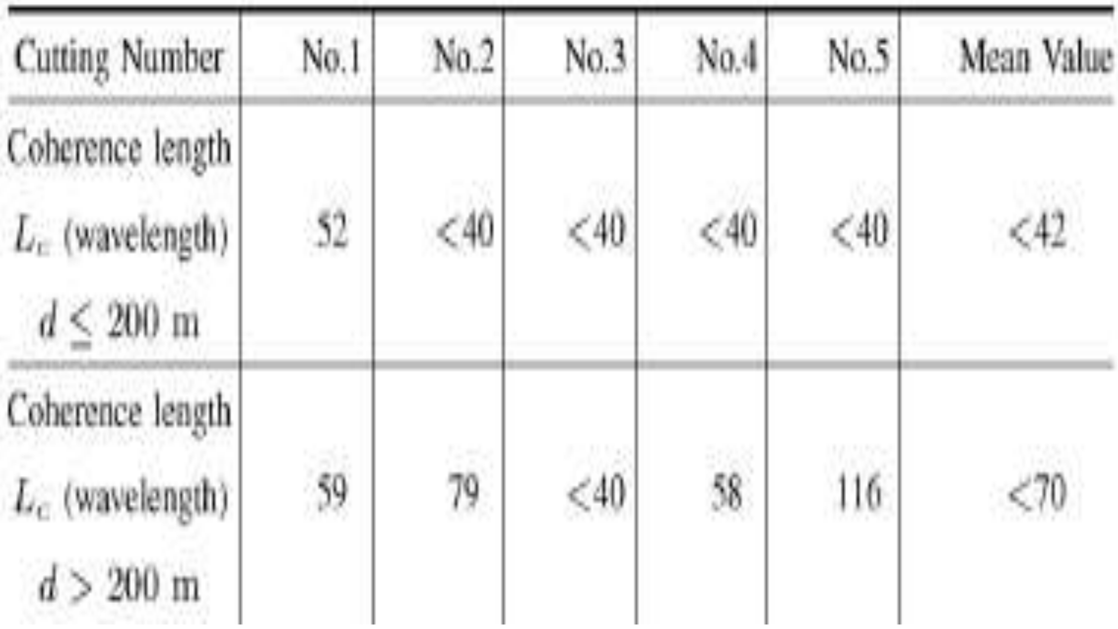


Figure 3: Different cuttings dimension

The result was compare with the measurement result given in He R, *et al.* (2013) as shown in table II and figure 3.

Table 2: Coherence length for each cutting He R, *et al.* (2013)



Cutting Number	No.1	No.2	No.3	No.4	No.5	Mean Value
Coherence length L_c (wavelength) $d \leq 200$ m	52	<40	<40	<40	<40	<42
Coherence length L_c (wavelength) $d > 200$ m	59	79	<40	58	116	<70

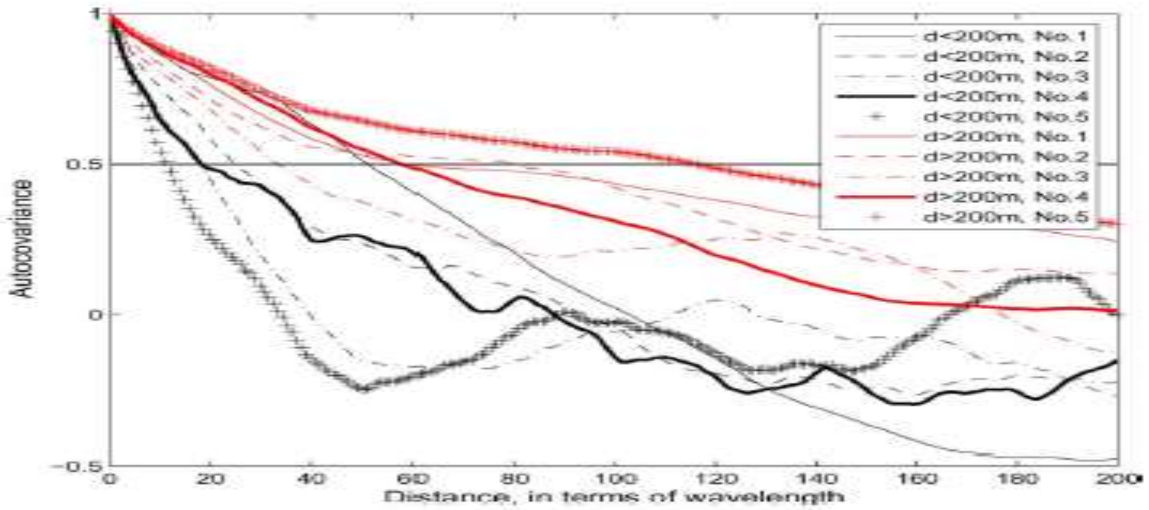


Figure 4: Auto covariance function *He R,* et al. *(2013)*

The result of figure 3 and table II in He R, *et al.* (2013) shows that when distance (wavelength) is less than 200m the autocorrelation function decay faster than when the distance (*d)* is greater than 200m. the value of coherence length is shown on the table above. This means that the Lc is less than 42λ, for $d \le 200$m and less than 70λ for $d > 200$m. the higher value of Lc for $d > 200$ m is caused by the dominant LOS path. The result obtained was compared with the measurement results obtained in He *et al.*, 2013), it was discovered that the result is in agreement with what was explained earlier on.

CONCLUSION

The impact of cutting scenario on radio channel characteristics of HST wireless communication system has been investigated. Four geometric key parameters (Width up, Width down, Slopes and Vegetation) which affect HST wireless communication system in cutting scenario also has been identified and investigated. It was discovered, that as the sum of width up and width down of cutting scenario increases the value of Ricean K-factor increases, which also lead to increase in the line of sight (LoS) consequently reduce the Non-line of sight (NLoS) as the number of scatterers reduces. The second parameter investigated was the effect of cutting slopes on HST wireless communication. It was found out that as the slopes of cutting increases the sum of W_{up} and W_{down} increases and the value of K factor increases, as mentioned above, the surface of cutting also matters a lot, Most HST cuttings are sleepy and a plane surface which causes reflection, diffraction of propagated signals. It was noticed that the slopes of cuttings, the sum of W_{up} and W_{down} of cuttings affect the K-factor and the time varying distance between the MRS and BS. All these affect the statistical properties which also have a direct impact on the wireless communication system.

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