MASSIVE MIMO FOR HIGH-SPEED TRAIN COMMUNICATION SYSTEMS

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Abstract: *With the current development in wireless communications in high-mobility systems such as high-speed train (HST), the HST scenario is accepted as among the different scenarios for the fifth generation (5G). Massive Multiple-Input-Multiple-Output (MIMO) systems, which are equipped with tens or hundreds of antennas has become an improved MIMO system which can assist in achieving the ever-growing demand of data for 5G wireless communication systems. In this study, the associated 5G technologies as well as the equivalent channel modelling in HST settings and the challenges of deploying massive MIMO on HST was investigated The channel model was modelled using the WINNER II channel model. With regrads the proposed non-stationary IMT-A massive MIMO channel models, the essential statistical properties such as the spatial cross-correlation function (CCF), local temporal autocorrelation function (ACF) of the massive MIMO channel model using different propagation scenarios such as open space, viaduct and cutting was analysed and investigated. The results from the simulations was compared with the analytical results in other to show that the statistical properties vary with time as a result of the non-stationarity of the proposed channel model. The agreement between the stationary interval of the non-stationary IMT-A channel model and the HST under different propagation scenarios shows the efficiency of the proposed channel model. Based on findings; the impact of the deployment of large antenna on the channel capacity should be thoroughly investigated under different HST propagation scenario. Also, more HST train propagation scenarios such as the tunnel, hilly terrain and the station should be considered in the non-stationary IMT-A massive MIMO channel models.*

Keywords: *Communication, High Speed, Massive, MIMO, Systems*

1.0 Introduction

The focus of mobile communication research, development and operation has since been on spectrum efficiency, the spatial multiplexing discovery through the use of multiple antennas in the mid-1990s brought new achievement to data rate boosting despite the limited bandwidth. Recently, it has become standard to equip the Base Stations (BSs) with an antenna array that aid various functionalities of the Massive Multiple-Input-Multiple-Output (MIMO) systems MIMO which includes; the multiplexing, diversity, beam forming, and interference coordination (Xiang Cheng *et al.*, 2014).

The MIMO recently draws much attention as an advancing methodology which can improve the result, reliability of the link and capacity, link rates, enhance the network throughput of the communication system, which is also to mainly increase the spectral efficiency of the communication system (Ghazal, 2017; Xie *et al.*, 2015).

In the evaluation and designing of MIMO wireless communication system, channel modelling performs an essential role, the demonstration of the feasibility of the wireless system cannot be realised without the precise channel model, which have the capability of mimicking the important features of the wireless channels (Ghazal, 2017).

MIMO is deployed in a lot of advanced wireless communication system such as the Long-term evolution (LTE), Worldwide Interoperability for the microwave access (WiMAX) etc. (Wu *et al.*, 2015). There are many standardised MIMO channel model such as the long term evolution-advanced (LTE-A), 3rd generation partnership project (3GPPP/3GPP2) spatial channel model (SCM), WINNER I, WINNER II, WINNER +, IMT-A channel models as well as SCM-Extension (SCME) (Ghazal, 2017; Wu *et al.*, 2015); but most of this mention channel models cannot sufficiently be able to capture specific characteristics of massive MIMO (Wu *et al.*, 2015), they neglect the non-stationarity of the fading channels which assumes that the network satisfies the wide sense stationary (WSS) (Ghazal, 2017).

The recent introduction of massive MIMO systems that are furnished with tens or hundreds of antennas is mostly and broadly recognised as one of the most important technologies which emerged as an improved MIMO technique to the increasing traffic demand for the 5G wireless communications (Wu *et al.*, 2014; Bai *et al.*, 2017). The massive MIMO system has more benefits than the conventional MIMO systems with less number of antennas, the performances of the system regarding capacity, reliability and energy efficiency and spectral efficiency is considerably better than the conventional MIMO systems (Wu *et al.*, 2014; Zhang *et al.*, 2017).

The massive MIMO channel system is not only equipped with tens or even hundreds of antennas, but it has a peculiar channel characteristics that include the non-stationary channel characteristics in time and array domain, spherical wavefront propagation which is modelled in the massive MIMO channel model in decreasing the correlation of the Channel Impulse Responses (CIRs) thereby increasing the capacity of the channel (Xie *et al.*, 2015; Bai *et al.*, 2017).

The large scale and the small scale fading which has a significant impact on the system performance of the 5G wireless system will be looked into (Wu *et al.*, 2014; Wu *et al.*, 2017). HST communication system also draws the attention for the emerging advancement for high mobility trains with an expected speed of over 500km/hr (Wu *et al.*, 2017). The high-speed mobile wireless communication systems encounter the challenge of providing constant communication services over fast-changing radio channel unfavourable environmental scenarios such as a tunnel, viaduct, subway and so on (Ghazal, 2017).

Due to the high mobility and non-stationarity of HST, massive MIMO will be deployed on the HST to enhance the data throughput, spatial efficiency of the channel will be modelled under different HST propagation scenarios. WINNER II as well as IMT-A channel model which uses the geometry-based stochastic models (GBSMs) channel model will be used to model the HST channels under different propagation scenarios where the comprehensive illustrations of the propagation for the environments couple with the computational resources will be required (Ghazal, 2017).

With regards the non-stationary IMT-A massive MIMO channel model, the statistical characeristics such as the spatial CCF, autocorrelation function (ACF) will be investigated as well as evaluated, and the static interval of the proposed channel model will also be investigated (Ghazal, 2017). The results gotten from simulation will be compared with the analytical results in other to demonstrate the efficiency of the proposed channel model.

It is against this background that this study attempts to investigate the deployment of massive MIMO technique on HST under different propagation scenarios such as; the open space, viaduct and the cutting. Also to investigate the associated 5G important technologies as well as the equivalent channel modelling within HST settings that lead to increasing demand for data of the 5G wireless communications.

2.0 Literature Review

The prediction for the mobile traffic is to grow more than 1000 times in the next 10 years, which the International Mobile Telecommunication (IMT) alongside with vision 2020 and beyond desires a future 5G wireless communication systems to be able to deliver a peak data rate of 10Gps, this leads to emergence of the massive MIMO technology (Jianhua, 2017).

The use of multi-users MIMO gives huge advantages over the conventional point-to-point MIMO, the multi-user works with inexpensive single-antenna terminals which do not require rich scattering environment, and the allocation of resource is simplified because every active terminal utilises all of the time-frequency bins (Larsson *et al.*, 2014). Although multi-user MIMO originally anticipated that the use of roughly equal numbers of service antenna, terminal and frequency-division duplex (FDD) is not an adaptable technology (Larsson *et al.*, 2014).

Massive MIMO system has a large number of the antenna which is typically tens or hundreds that serves many tens of terminals that have the same time-frequency resource. It provides better performance in spectrum efficiency, reliability, robust and channel capacity; it is also used as an enabler for infrastructure for the future digital society that will connect the internet of things and internet of people with the clouds and also with other network infrastructures (Jianhua, 2017; Larsson *et al.*, 2014).

Series of measurement campaign of massive MIMO has been carried out to evaluate the performance of the channel, for example, the outdoor channel measurement with a linear virtual array and cylindrical array of 128 antennas elements and carrier frequency of 2.6GHz which studied the capacity, sum rate, precoding schemes and spectrum efficiency, and also an outdoor static measurement campaign in a stadium was performed and analysed with the use of a linear 128 antenna element virtual array with frequency of 1.4725GHz and an angular power spectrum was used in the massive MIMO measurement (Jianhua, 2017).

2.1 High-Speed Train (HST)

High-Speed Train, also called High-Speed Railway is known for bringing comfort to the lives of people, it is famous as the most viable developments for ground transportation, the signalling system which is also called the operation control system is one of the important parts of the HST construction where the wireless communication performs an important role in the transmission of data for the train control (Ai, 2014). The growth of HST in the world has made the maximum moving speed of the train to reach nearly 575km/h, the issue of safety in the train operation has drawn more attention due to the increase in the train speed (Ai, 2014). The three main part contributing to the safe operation of the HST is namely: the ground infrastructure (e.g. trackside equipment), the moving body (e.g. the train), and the signalling system. Out of the three main parts, the signalling system which is also called the operation control system of the train is an important part of the train which is regarded as the HST system nerve centre (Ai, 2014).

Global system for mobile communications for railway (GSM-R) which is a narrow-band communication system performs an important role in the safe operation of the HST to make the operation of the train control system to work better and also to maintain a reliable link in communication between the train and the ground (Ai, 2014). In Ai (2014), the long-term evolution of railway (LTE-R) that is a broadband system of communication was also deployed due to the fast growth in the railway service.

HST scenario which is one of the high-mobility scenarios is expected to be one of the typical 5G communication systems, due to the fast development in the HST, increasing the capacity of data for wireless communication is needed to be transmitted to the commuters on the train (Wang *et al.*, 2016). The HST users requires sufficient network with reliable communication services regardless of their location and the speed of the train, in order to satisfy this requirement, HST wireless communication system has to overcome several challenges due to the effect of the high speed of the train which could simply go beyond 250km/h; some of the challenges are; fast travel through different scenarios, doppler spread, fast handover and also certain constraints originating from orthodox trains for example; inadequate visibility within subways, harsh electromagnetic environment and high penetration losses (Wang *et al.*, 2016; Ghazal *et al.*, 2016).

In Ai (2014), it was stated that whether the system of communication in the HST is GSM-R, an LTE-R or an IEEE 802. 15.4p, to get a reliable communication, the most important condition is to have the full understanding of the propagation properties of the wireless channels; wireless channel modelling is an essential basis and a vital means for planning and optimization for communication network, the design of the transmitter and receiver and also the physical and upper layer in choosing the important technologies (Ai, 2014).

Many research studies on wireless channel measurement and modelling were performed; for example Rappaport *et al*. worked on 60GHz wireless communications and channel modelling, Matolak *et al*. studied on vehicle-to vehicle (V2V) channel modelling, Sivertsen *et al*., Cheng *et al*. and Guan *et al*. researched on the multi input-multi-output orthogonal frequency-division multiplexing (MIMO-OFDM) channel modelling, ray-tracing technique and geometry-based stochastic channel modelling (GBSM); lots of works on channel modelling, supply of channel measurement instruments and standardization were done by project groups such as COST, WINNER and MEDAV (Ai, 2014).

2.1.1 Classification of different scenarios in HST

The transmitter and receiver for the HST wireless communication system are faced with different challenges in the channel condition because the train has to pass through various scenarios and geographical environment. The different environment could be categorised into six(6) scenarios such as; cutting, open space, tunnel, viaduct, stations as well as hilly terrain (Wang *et al.*, 2016; Ghazal *et al.*, 2016); Figure 1 shows further classification of the HST scenarios.

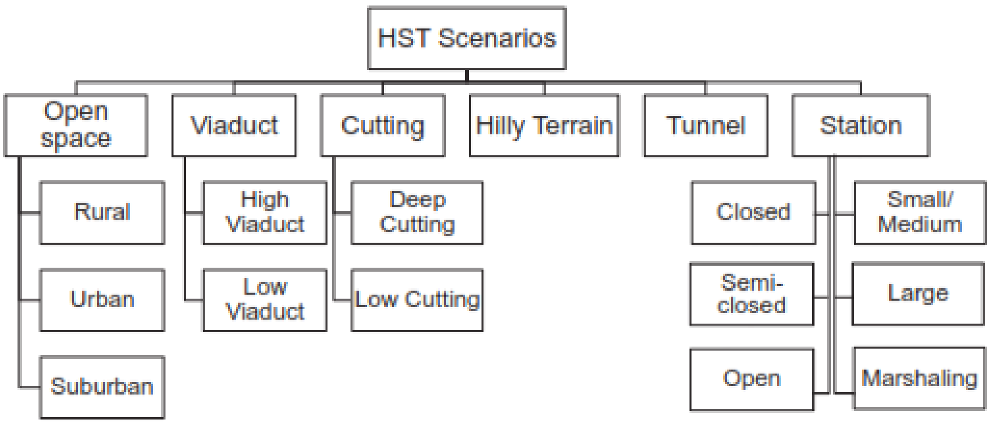

Figure 1: The classification of HST scenarios

2.2 Massive MIMO

Massive MIMO which is also known as large-scale antenna system, hyper MIMO, very large MIMO, ARGOS and full dimension MIMO is an emerging technology where tens and hundreds of antennas give greater performance in reliability, capacity, efficiency. Massive MIMO is also robust against unintended man-made interference; it can improve the channel capacity, reduce latency on the air interface and international jamming (Jianhua, 2017; Larsson, 2014), (Gao *et al.*, 2013; Wang *et al.*, 2016). Massive MIMO considers the multi-user MIMO (MU-MIMO) where the BS is equipped with arrays of antennas (tens and hundreds of antennas) that is serving many tens of terminals in the same time-frequency resources (Larsson, 2014; (Gao *et al.*, 2013; Wang *et al.*, 2016).

Massive MIMO is an enhanced MIMO technique that is used to meet the increasing traffic demand of the 5G wireless communication network; massive MIMO has some benefits as compared to conventional MIMO such as;

- Sufficiently increasing the energy efficiency as power is concentrated in a sharp direction.
- Boosting of the system throughput by the utilisation of MU-MIMO, the introduction of a huge number of antennas according to the large number theorem reduces the interference between users.
- Reduction in the cost of implementation by including the simplification of medium-access control layer and by the use of low-cost antenna elements as a result of very large MU-MIMO and beamforming gain.
- Massive MIMO offers more degree of freedom because it is more robust than the conventional MIMO systems (Wu *et al.*, 2014; Larsson, 2014; Wang *et al.*, 2016).

Massive MIMO depends on spatial multiplexing which in turns depends on the BS to have better knowledge of the channel on both uplink and downlink. In the uplink, it is easy to accomplish because the terminals send pilots based on which the BS estimates the response of the channel response to every terminal, but in downlink, it is more difficult (Larsson, 2014).

Massive MIMO is used to enable the development of the future broadband networks that are energy efficient, robust, secure and that will use the spectrum efficiency. It is also an enabler for the digital society infrastructure in the future that will connect the internet of things and internet of people with clouds and other infrastructures (Larsson, 2014).

Both theory and real propagation environments have shown that massive MIMO systems have very promising properties due to its many benefits such as energy efficiency, highly improving the spectral efficiency and robustness of the system as compared to the orthodox MIMO frameworks that have a minute proportion of antennas at the BS (Gao *et al.*, 2013; Wang *et al.*, 2016). To efficiently evaluate the new technique in massive MIMO in more practical settings, new channel models are required to showcase the essential characteristics of the real massive MIMO channels for propagation. Massive MIMO can have antenna arrays that span tens or hundreds of wavelength in space due to its large number of antennas (Gao *et al.*, 2013).

The novelty of this research is the deploying of massive MIMO on HST and using the WINNER II channel model in modelling the channel. Regrading the non-stationary IMT-A massive MIMO channel models, the statistical elements such as; local temporal ACF as well as spatial CCF will be derived and evaluated under different HST propagation scenarios such as; cutting, viaduct as well as the open space. The stationary interval of the proposed channel model will be investigated and will be compared with the original non-stationary IMT-A MIMO channel model in other to demonstrate the efficiency of the proposed channel model.

3.0 Methodology

In this study, massive MIMO technique was deployed on HST under different scenarios; the radio channel was modelled under the HST wireless communication system with different propagation scenarios such as the open space, viaduct and cutting. The massive MIMO characteristics such as the non-stationarity and the spherical wavefront of the channel was captured and investigated.

The GBSMs channel model was used in modelling of the massive MIMO on HST channel model. GBSMs is one of the recent advances in conventional MIMO systems, although the channel model can model the MIMO channels more accurately taking into consideration the key characteristics of the channel, it has higher computational complexity (Wang *et al.,* 2016).

The non-stationarity properties of the clusters such as the appearance and disappearance on the time axes and the array was modelled by the use of birth-death process and the impact of the spherical wavefront on the Doppler frequencies on the antenna array as a results of increased number of antennas was captured (Gao *et al.,* 2013; Wang *et al.,* 2016).

The IMT-A system using the WINNER II channel model was adopted on the HST wireless communication system under the open space, viaduct and the cutting scenarios. Key statistical properties for instance, the local temporal ACF, local spatial CCF, was formulated as well as evaluated, the correlation and the effect on the channel capacity for the different scenarios was compared, and non-stationarity interval of the channel model was also investigated (Ghazal, 2017).

The mobile relay technology that was adopted by the IMT-A system and the WINNER II channel model was used in the deployment of the massive MIMO system on the HST, dedicated MRS was deployed on the roof of the train in other to stretch the area of coverage at the outdoor Base Station into the coaches of the train, this leads to having two channels which are; an outdoor channel between the BS as well as the MRS, and an indoor channel between the MS and the MRS which is illustrated in Figure 2 (Wang *et al.,* 2016; Ghazal, 2015).

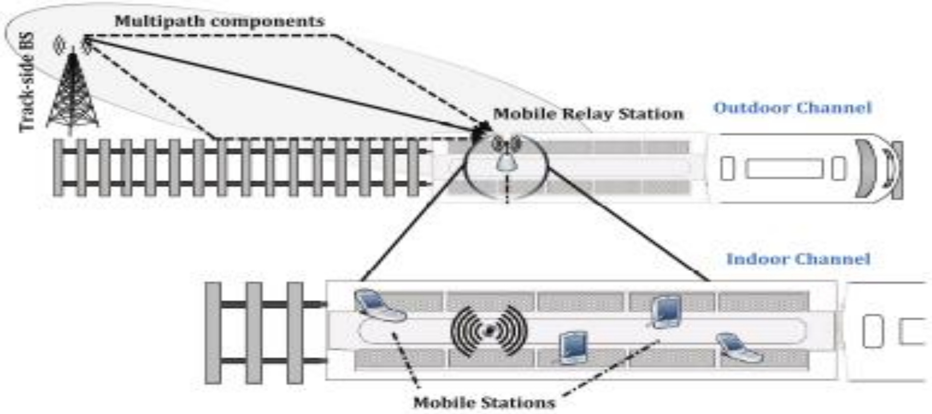

Figure 2: Deployment of MRSs on HST communication system

From Figure 2, the BS principally have communication with the MRS at high data rate rather than directly communicating with large numbers of MRSs, the MRSs together with the MSs inside the train coaches are entirely seen as one component to the BS whereas MRSs views the relevant MRSs as a normal BS. The repeated handover problem on HST systems can greatly be reduced by the MRS performing a collection of handover in respect of the related MSs (Wang *et al.,* 2016).

In the IMT-A systems where the generic model which is based on WINNER II channel model gives the detailed algorithms as well as the mathematical model that are utilised for the channel modelling in every settings, the model makes use of the GBSM approach in representing the multipath propagation channel between BSs to the MSs (Ghazal, 2017). The channel in IMT-A channel model is pressumed to provide all that is needed for the WSSUS assumption that signifies that the statistics of the channel fading remains invariant in the time domain over a short period where the scatterers with diverse route delays are uncorrelated, based on the statement of the WSSUS and the concept of the tap delay line (TDL), the complex CIR between antenna element s(s = 1, …, S) of the BS as well as the antenna elements u(u = 1, …, U) of the MS of the IMT-A MIMO channel model is given as (Ghazal, 2017);

$$h_{u,s}(t,\tau) = \sum_{n=1}^{N} h_{u,s,n}(t)\delta(\tau - \tau_n) \tag{1}$$

Where,

$$h_{u,s,n}(t) = \sqrt{\frac{P_n}{M}} \sum_{m=1}^{M} e^{jd_s k \sin(\phi_{n,m})} e^{jd_u k \sin(\varphi_{n,m})} \times e^{j2\pi v_{n,m} t} e^{j\Phi_{n,m}}. \tag{2}$$

In this equation $h_{u,s,n}(t)$ $(n = 1, \ldots, N)$ signifies a narrow procedure whereby every one of the M sub-paths in every N-clusters are irresolvable rays that possess similar delay τ_n, the power of the nth cluster connected with the delay τ_n, is given as P_n, the antenna element spacing at the BS and the MS is given as d_s and d_u respectively, the wave number is $k = \frac{2\pi}{\lambda}$ where λ is the carrier wavelength, the AoA as well as AoD associated to the $mth(m = 1, \ldots, M)$ ray within the $nth(n = 1, \ldots, N)$ cluster is given as $\phi_{n,m}$ and $\varphi_{n,m}$ correspondingly as well as the random stages $\Phi_{n,m}$ are distributed uniformly within [- π, π]. The Doppler frequency unit is given through $\frac{||\bar{v}MS|| \cos(\varphi_{n,m} - \theta_{MS})}{\lambda}$ where $||\vec{v}_{MS}||$ and θ_{MS} represents the magnitude of the MS velocity as well as direction of travel for the MS correspondingly, every of the factors mentioned above are time-invariant due to the fact that the WSSUS assumption of the IMT-A channel model (Ghazal, 2017).

3.1 The non-stationary IMT-A channel model with the time-varying parameters

Due to the noticeable movement of the MC and MSs, the assumption for WSSUS will be violated while the channel parameters changes with time, the CIR of the non-stationary IMT-A channel model with time-variable factors, in this case, could be represented as;

$$h_{u,s}(t,\tau) = \sum_{n=1}^{N(t)} h_{u,s,n}(t)\,\delta(\tau - \tau_n(t)) \tag{3}$$

where

$$h_{u,s,n}(t) = \sqrt{\frac{P_n(t)}{M}} \sum_{m=1}^{M} e^{jd_s k \sin(\phi_{n,m}(t))} e^{jd_u k \sin(\varphi_{n,m}(t))} \times e^{jk||\vec{v}_{MS}|| \cos(\varphi_{n,m}(t) - \theta_{MS})t} e^{j\Phi_{n,m}}. \tag{4}$$

As a result of the movement of the MC and the MSs, the parameters of the channel $N(t)$, τ_n, $P_n(t)$, $\phi_{n,m}(t)$, and $\varphi_{n,m}(t)$ changes with time and hence, requires to be expressed utilising appropriate time-variable functions, the IMT-A channel model is illustrated in Figure 3 (Ghazal, 2017).

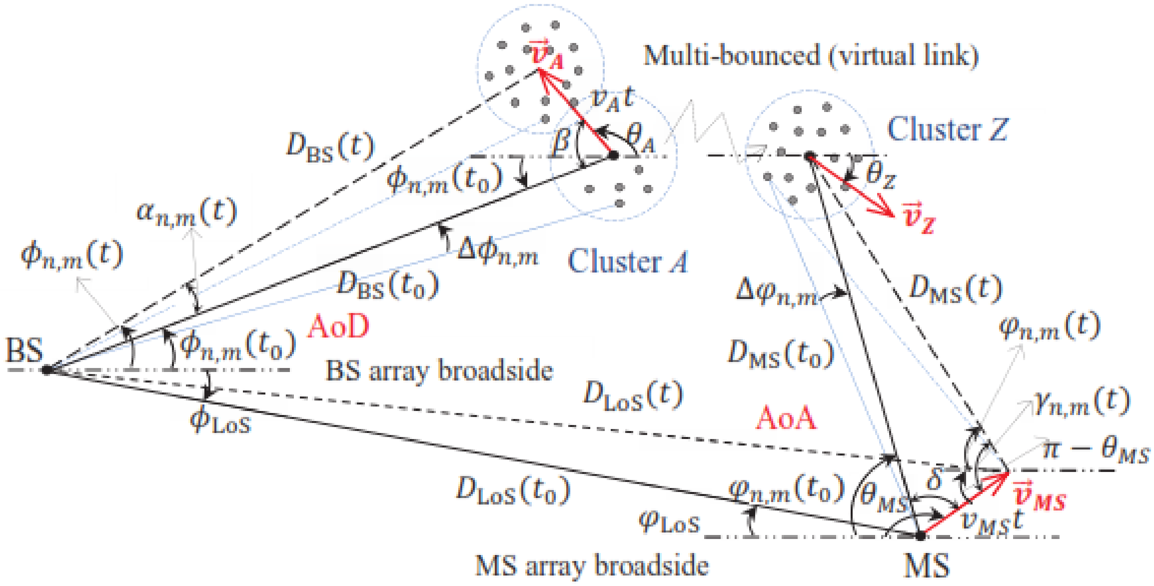

Figure 3: Angular parameters for MS and BS within the IMT-A channel model

In this channel, the propagation between the first as well as the latter related cluster is not defined, although multiple interactions with scattering media can also be model in the same way. Note that the primary AoA, initial AoD, AoA offset as well as AoD offset is given as, $\varphi_{n,m}(t_o)$, $\phi_{n,m}(t_o)$, $\Delta\varphi_{n,m}(t_o)$, $\Delta\phi_{n,m}(t_o)$ respectively, one of the N path as well as one of the M ray/sub-paths within the wideband channel model is indicated by the subscripts n, m respectively (Ghazal, 2017).

The first bounce/cluster (i.e. cluster A) describes the AoD which is related from the BS side as well as the last bounce/cluster (i.e. cluster Z) describes the AoA, in addition, the LoS components for the BS and MS are denoted by ϕLoS, and φLoS respectively, from Figure 3 it is assumed that the BS is static and the first cluster, Cluster A is moving with the direction θ_A as well as with the speed of v_A (Ghazal, 2017). The multi-bounced scattering which takes place from each path is been considered as the last bounce MC and is referred to as Cluster Z with the moving direction θ_Z and the speed v_Z, for the MS, the moving direction is given as θ_{MS} and speed v_{MS}, the vectors $\vec{v}_A$, $\vec{v}_Z$ and $\vec{v}_{MS}$ represents the movement of MC Z, MS and MC A in Figure 3. The earlier gap between the MC A and BS and the earlier distance between the MC Z and MS which are given as $D_{BS}(t_o)$ and $D_{MS}(t_o)$ are presumed to be recognized, and the prior distance of the LoS units between the MS and the BS is given as $D_{LoS}(t_o)$ (Ghazal, 2017).

Four assistant angles are sets in Figure 3 in other to derive the time-varying angular parameters, they are; $\alpha_{n,m}(t)$, β, $\gamma_{n,m}(t)$ and δ, note that only LoS path and the nth scattered propagation path are presented in the Figure 3. For example, Cluster A corresponds to the first bounce while Cluster Z corresponds to the last bounce of the nth scattered path, if MC Z as well as MC A is static, the speed v_A of the MC A and speed v_Z of MC Z can be set to zero and this will not affect the generation procedure of the channel coefficients within the non-stationary IMT-A MIMO channel model (Ghazal, 2017).

Based on the geometric description of the channel above, Figure 4 illustrates the procedure to obtain the channel realization of the non-stationary IMT-A channel model where the initial values of the channel model parameters such as $\tau_n(t_o)$, $P_n(t_o)$, $\phi_{n,m}(t_o)$, and $\varphi_{n,m}(t_o)$, are calculated using the same procedure represented within the original IMT-A channel model (i.e. at the topmost segment of Figure 4) (Ghazal, 2017).

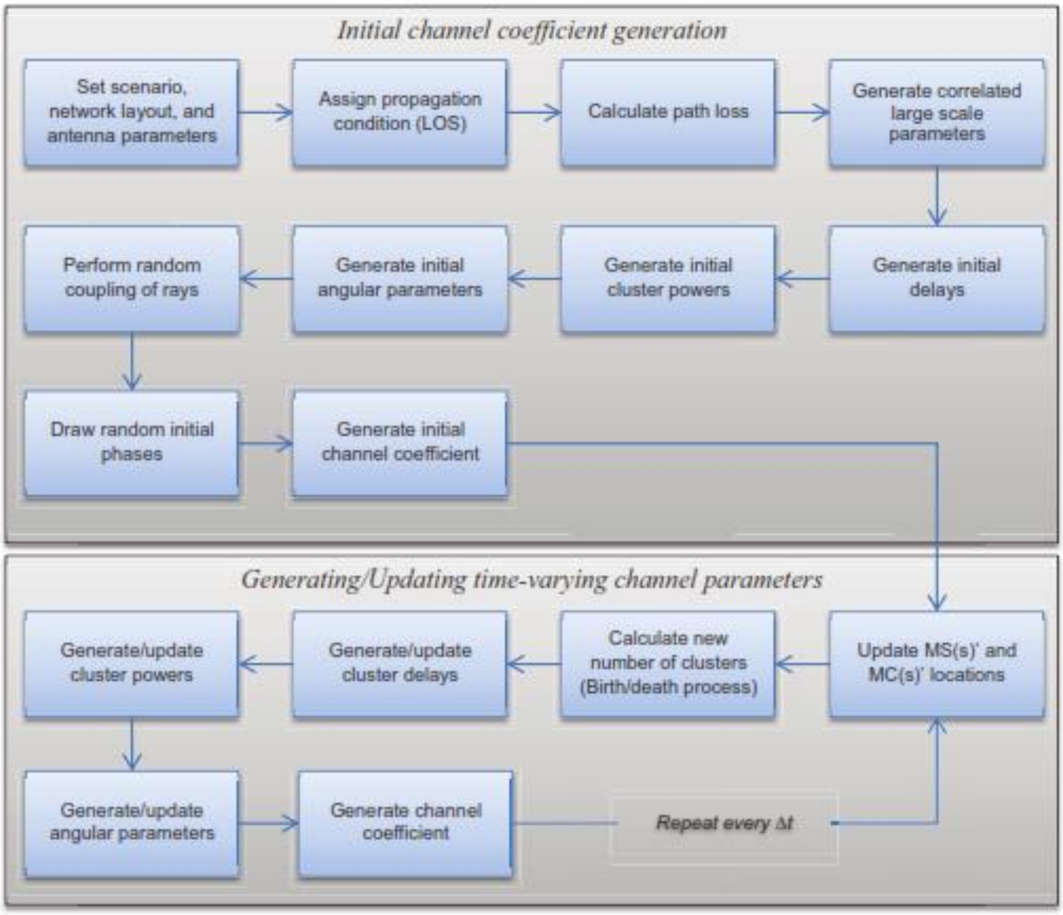

Figure 4: Generation procedure for the non-stationary IMT-A channel coefficients

The focus here will be on the non-stationarity characteristics of the IMT-A channel model (which is at the lowest segment of Figure 3) (Ghazal, 2017).

3.2 The stationary interval of the channel model

The average power delay profiles (APDPs) is used in calculating the stationary interval of the channel model, and it is given as;

$$\overline{P_h}(t_k,\tau) = \frac{1}{N_{PDP}} \sum_{k}^{k+N_{PDP}-1} |h_{u,s}(t_k,\tau)|^2 \tag{35}$$

Where N_{PDP} denotes the proportion of power delay profiles to be averaged, *tk* is the time of the *kth* drop and $h_{u,s}(t_k,\tau) = \sum_{n=1}^{N} h_{u,s,n}(t_k)\delta(\tau-\tau_n)$.

The correlation coefficient between two APDPs could be determined as [2]

$$c(t_k,\Delta t) = \frac{\int \overline{P_h}(t_k,\tau)\,\overline{P_h}(t_k+\Delta t,\tau)\,\mathrm{d}\tau}{\max\{\int \overline{P_h}(t_k,\tau)^2\,\mathrm{d}\tau, \int \overline{P_h}(t_k+\Delta t,\tau)^2\,\mathrm{d}\tau\}}. \tag{36}$$

Therefore, the stationary interval can be calculated as

$$T_s(t_k) = \max\{\Delta t|_{c(t_k,\Delta t)\geq c_{\text{thresh}}}\} \tag{37}$$

Where the threshold of the correlation coefficient is given as c_{thresh} (Ghazal, 2017).
The documentation for the source code for MATLAB implementation for WINNER II channel model from reference was used for writing the MATLAB programs that was used to perform the simulation for the channel model. The channel model parameters for the scenarios were set up in accordance the ITU-R M.2135-1 (Report ITU-R M.2135-1, 2009).
Table A1-7 in the ITU-R M.2135-1 (Report ITU-R M.2135-1, 2009) was used for the channel parameter setup; the table was upgraded by the addition of viaduct and the cutting scenarios.

From the table A1-7 in the ITU-R M.2135-1 (Report ITU-R M.2135-1, 2009), the following are represented as;
DS: rms delay spread, ASD: rms azimuth spread of departure angles, ASA: rms azimuth spread of arrival angle, SF: shadow fading and K: Ricean *K*-factor. The sign for the shadow fading is defined such that the positive SF means more received power at the UT than predicted by the path loss model (Report ITU-R M.2135-1, 2009).
The DS, SF and the K-factor for the new scenarios were obtained from channel measurements on HST; the channel measurements were obtained from references (Guo *et al.*, 2013) for the viaduct, (Tian *et al.*, 2013 and Sun *et al.*, 2013) for the cutting scenario.

Table 1: Channel model parameters setup

SCENARIOS		**RMa (Open Space)**		**Viaduct**		**Cutting**	
		LoS	**NLoS**	**LoS**	**NLoS**	**LoS**	**NLoS**
Delay spread (DS) $\log_{10}$(s)	μ	-7.49	-7.43	-7.04	-7.43	-6.71	-7.43
	σ	0.55	0.48	0.54	0.48	0.40	0.48
AoD spread (ASD) $\log_{10}$(degrees)	μ	0.90	0.95	0.90	0.95	0.90	0.95
	σ	0.38	0.45	0.38	0.45	0.38	0.45
AoA spread (ASA) $\log_{10}$(degrees)	μ	1.52	1.52	1.52	1.52	1.52	1.52
	σ	0.24	0.13	0.24	0.13	0.24	0.13
Shadow fading (SF) (dB)	σ	4	8	4.8	8	1.66	8
K-factor (*K*) (dB)	μ	7	N/A	8.78	N/A	0	N/A
	σ	4	N/A	6.08	N/A	3.23	N/A
Cross-correlation*	ASD vs DS	0	-0.4	0	-0.4	0	-0.4
	ASA vs DS	0	0	0	0	0	0
	ASA vs SF	0	0	0	0	0	0
	ASD vs SF	0	0.6	0	0.6	0	0.6
	DS vs SF	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
	ASD vs ASA	0	0	0	0	0	0
	ASD vs *K*	0	N/A	0	N/A	0	N/A
	ASA vs *K*	0	N/A	0	N/A	0	N/A
	DS vs *K*	0	N/A	0	N/A	0	N/A
	SF vs *K*	0	N/A	0	N/A	0	N/A
Delay distribution		Exp	Exp	Exp	Exp	Exp	Exp
AoD and AoA distribution		Wrapped		N/A		N/A	

		Gaussian					
Delay scaling parameter r_τ		3.8	1.7	3.8	1.7	3.8	1.7
XPR (dB)	μ	12	7	12	7	12	7
Number of clusters		11	10	11	10	11	10
Number of rays per cluster		20	20	20	20	20	20
Cluster ASD		2	2	2	2	2	2
Cluster ASA		3	3	3	3	3	3
Per cluster shadowing std ζ (dB)		3	3	3	3	3	3
Correlation distance (m)	DS	50	36	50	36	50	36
	ASD	25	30	25	30	25	30
	ASA	35	40	35	40	35	40
	SF	37	120	37	120	37	120
	K	40	N/A	40	N/A	40	N/A

4.0 RESULTS

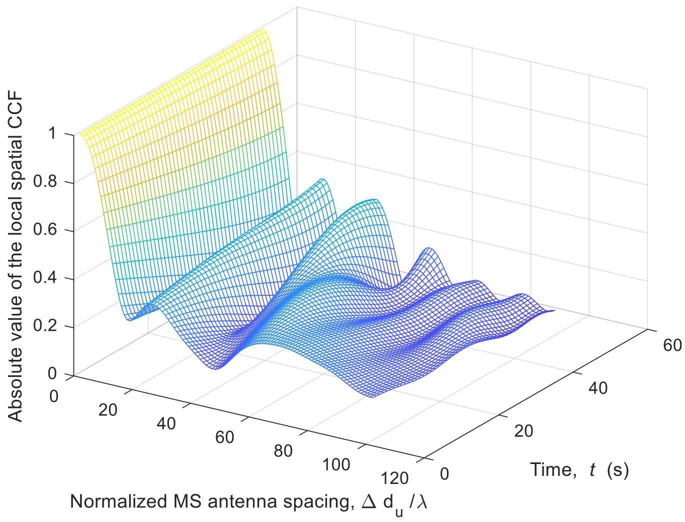

Figure 5: The plot for the absolute value of the local spatial CCF of the non-stationary IMT-A massive MIMO channel model for the open space scenario

The LoS propagation condition for the open space scenario, having the key simulation parameters as follows; $\phi_{n,m}(t_o) =$ random, $D_{BS}(t_o)$ = 100m, $\theta_A = 15^0$, v_A = 30m/s, $\varphi_{n,m}(t_o)$ = random, $D_{MS}(t_o)$ = 150m, $\theta_v = 120^0$, and v = 20m/s (Ghazal, 2017). Figure 5 exhibits the absolute measure of the 3D local spatial CCF of the non-stationary IMT-A massive MIMO channel model, the figure clearly shows that the local spatial CCF changes with time as a result of the non-stationarity of the channel.

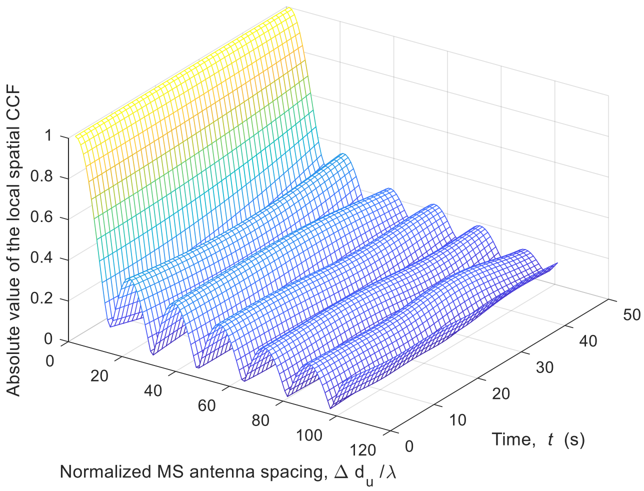

Figure 6: The plot for the absolute value of the local spatial CCF of the non-stationary IMT-A massive MIMO channel model for the viaduct scenario

By adopting the LoS propagation condition for the viaduct scenario, the key simulation parameters used are as follows; $\phi_{n,m}(t_o)$ = random, $D_{BS}(t_o)$ = 100m, $\theta_A = 15^0$, v_A = 30m/s, $\varphi_{n,m}(t_o)$ = random, $D_{MS}(t_o)$ = 150m, $\theta_v = 120^0$, and v = 20m/s (Ghazal, 2017). Figure 6 above presents the absolute values of the 3D local spatial CCF of the non-stationary IMT-A massive MIMO channel model, the figure clearly shows that the local spatial CCF changes quickly with time as a result of the non-stationarity of the channel.

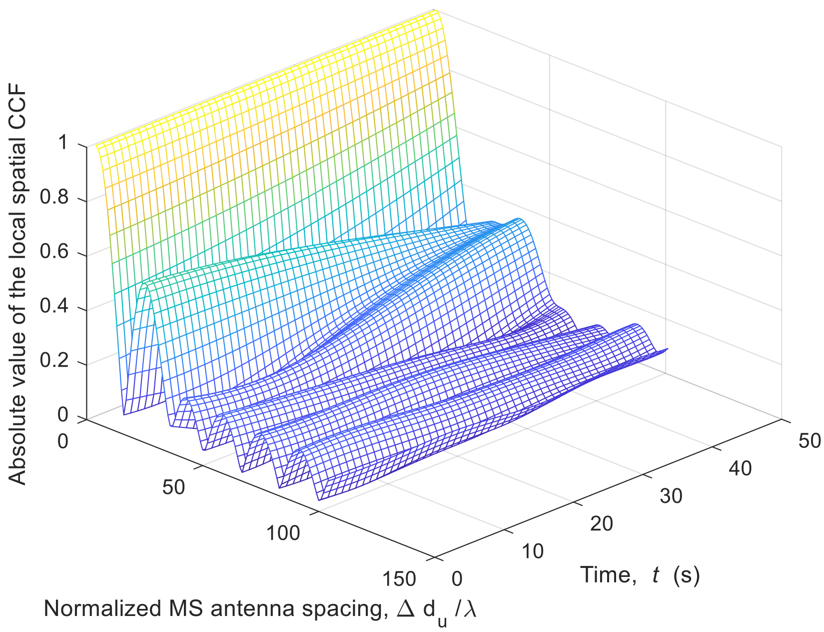

Figure 7: The plot for the absolute value of the local spatial CCF of the non-stationary IMT-A massive MIMO channel model for the cutting scenario

By adopting the LoS propagation condition for the cutting scenario, the key simulation parameters used are as follows; $\phi_{n,m}(t_o)$ = random, $D_{BS}(t_o)$ = 100m, $\theta_A = 15^0$, v_A = 30m/s, $\varphi_{n,m}(t_o)$ = random, $D_{MS}(t_o)$ = 150m, $\theta_v = 120^0$, and v = 20m/s (Ghazal, 2017). Figure 7 above presents the absolute values of the 3D local spatial CCF of the non-stationary

IMT-A massive MIMO channel model, the figure clearly shows that the local spatial CCF also changes with time as a result of the non-stationarity of the channel.

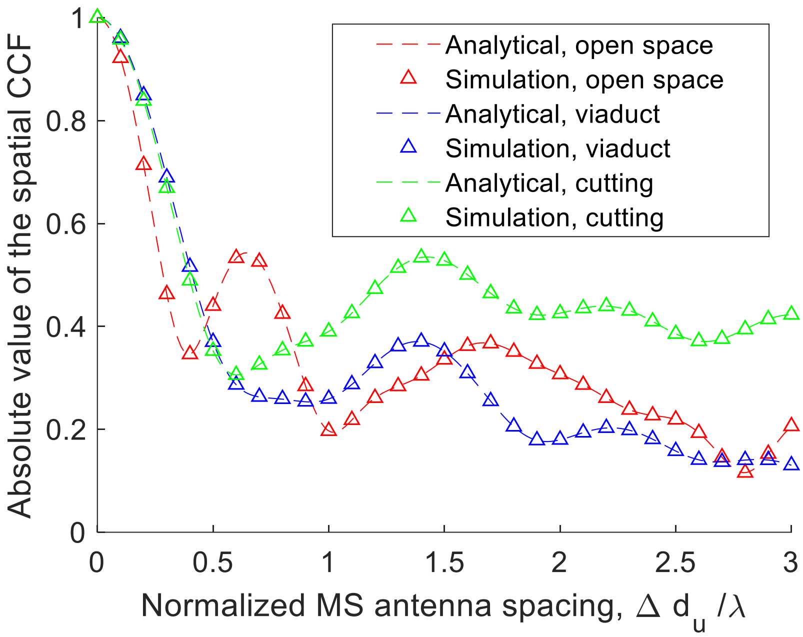

Figure 8: The plot to show the comparison of the local spatial CCFs of non-stationary IMT-A massive MIMO channel model for LoS propagation condition in open space, viaduct and the cutting scenario at t = 5s

Figure 8 shows the comparison between the 2D local spatial CCF for open space, viaduct and cutting scenario.

In the cutting scenario, the correlation is very high. This is as a result that the propagation of the radio waveforms is greatly impacted through the vertical walls and the vegetation on both side due to the U – shaped cut surface between the hills (Wang *et al.*, 2016), which will lead to reflection in the radio waves and more scattered components which leads to more correlation and hence, less channel capacity (Wang *et al.*, 2016; Ghazal *et al.*, 2016; Alshammari *et al.*, 2017; Fu, 2016).

In the open space scenario, the correlation is less than that of the cutting and higher than that of the viaduct scenario. This might be due to the NLoS propagation condition which is common in this scenario due to sparse scatterers such as buildings, vehicles that are noticed at the receiver side (Wang *et al.*, 2016), this scatterers may lead to diffraction in the signal which leads to more correlation between the antennas and hence, leads to less channel capacity (Alshammari *et al.*, 2017; Fu, 2016).

In the viaduct scenario, the correlation is very low; it is lower than that of the cutting and open space scenarios. This is based on the height of the BS which gives a clear LoS that reduces the impact of the scattering (such as buildings, trees), reflection and diffraction (Wang *et al.*, 2016) on the signal at the receiver and this, in turn, leads to less correlation between the antennas and hence, high channel capacity (Alshammari *et al.*, 2017; Fu, 2016).

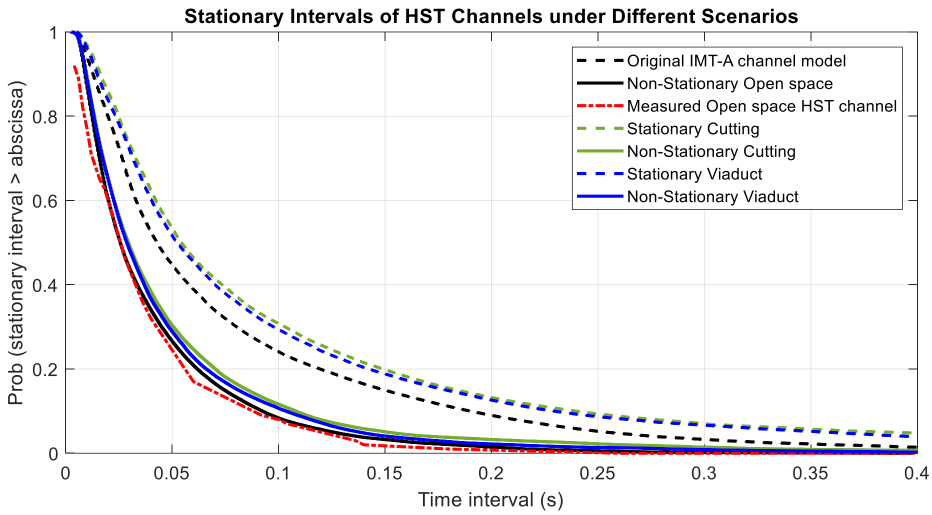

Figure 9: Stationary intervals of HST channels under different scenarios

Figure 9 above shows the plots for the stationary intervals of HST channel under different scenarios. The plots show the experimental complementary cumulative distribution functions (CCDFs) of the static intervals for the original IMT-A channel model, proposed non – stationary IMT-A channel model for open space, cutting as well as viaduct scenarios, and the measured open space HST channel model. The parameters that were used for the simulation are listed as follows: f_c = 930MHz, v = 90m/s and c_{thresh} = 0.8. The parameters for the non-stationary IMT-A channel model is; $D_{BS}(t_O)$ = 100m, v_A = 0m/s, $D_{MS}(t_O)$ = 70m, and θ_v = 0º. (Ghazal, 2017).

Note that the stationary interval in the proposed non-stationary IMT-A massive MIMO channel model depends on the movement variables such as; direction of the MS, the direction of the MC, AoD spread, AoA spread and so on (Ghazal, 2017).

From Figure 9, it is seen that the proposed channel model agrees well with the calculated channel model which functions as the viability of the proposed non-stationary IMT-A channel models under different HST scenarios. It can likewise be observed that the static intervals for the proposed IMT-A channel model under different HST scenarios and the measured HST open space channel model are considerably shorter than that of the original IMT-A channel model (Ghazal, 2017). A longer stationary interval is observed in cutting than the viaduct and the open space scenario; it might be due to the effect of the reflected and scattered components that are caused by the slopes of the cutting which affects the propagation condition (Wang *et al.*, 2016; Ghazal *et al.*, 2016). The changing in the surrounding environment due to the homogeneous nature of the steep walls of the cutting will affect the communication channel which will make it experience less changes in its propagated path between the transmitter and the receiver compared with the open space and the viaduct scenario.

5.0 Conclusion and Recommendations

5.1 Conclusion

A non-stationary IMT-A massive MIMO channel model has been proposed where the time differences, the channel capacity and the impact of correlation due to the large antenna array in massive MIMO was investigated under different HST propagation scenarios such as; and the cutting, viaduct, and the open space.

With regards to the proposed non-stationary IMT-A, massive MIMO channel model statistical characteristics such as the local temporal ACF as well as the local spatial CCF was investigated. The outcome of the simulation show that the statistical parameters differ with time as a result of the time-varying properties of the proposed non-stationary channel model. The analytical results were compared with the simulation results, and it was observed that there is credible pact between the simulation as well as the analytical results which verifies the accuracy of the analytical and the simulation result and also demonstrates the correctness of the proposed channel model.

The stationary interval of the proposed channel model under the open space, viaduct and the cutting scenario was also investigated regarding the APDP. The respective results of simulation prove that the static interval of the proposed non-stationary IMT-A massive MIMO channel model is suitable with the stationary interval of the measured channel model, as well as it is significantly shorter in comparison with the static interval of the original IMT-A channel model which demonstrates that the proposed channel model can mimic the characteristics of the high – mobility channels. From the results, it was also observed that the viaduct and the cutting has a longer stationary interval as compared to the open space.

5.2 Recommendations

The deployment of massive MIMO was to improve the channel capacity in other for the passengers on the train to have more data throughput, but the deployment of this large antenna array at the transmitter and the receiver has an impact on the channel capacity. The impact of the deployment of large antenna on the channel capacity should be thoroughly investigated under different HST propagation scenario. Also, more HST train propagation scenarios such as the tunnel, hilly terrain and the station should be considered in the non-stationary IMT-A massive MIMO channel models.

It is recommended that a non-stationary IMT-A massive MIMO channel model which will verify and investigate the small scale parameters such as; the cluster power, AoDs and AoAs should be considered.

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