The Study of Spatial-Time-Frequency Correlation Properties of 5G Channel Modeling of MIMO-OFDM System

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Abstract

The fifth generation (5G) mobile communication systems will have the speed more 100 times compared to the 4G and with the aim is to provide every propagation environment for every destination. Multiple-input multiple-output (MIMO) communication is the important technology researched for 5G systems. This paper studies the correlation properties of 5G channel modeling in MIMO system such as auto-correlation functions of time and frequency, as well as the spatial cross-correlation function. The scenarios UMi, RMa and indoor cells are investigated at 6 GHz frequency band in non-line of sight (NLOS) case. We calculate the spatial-temporal-frequency correlation functions of the 5G MIMO channel to estimate the system level in physic layer. From that, we conclude the minimum correlation values are depended on the distance of antenna elements in each transmitter and receiver side. We also identify the offset in time and frequency domains to identify the stability of the signal in a certain range.

Keywords: MIMO, 5G channel modeling, spatial cross-correlation, time auto-correlation, frequency auto-correlation

1. Introduction

3rd Generation Partnership Project (3GPP) channel model is one of the most well known in industry as well as with a large of research applications. Many propagation environments as UMi, UMa, indoor office… in the case of line of sight (LOS) and non-line of sight (NLOS) under the functions of probabilities, path loss models, path delays, and path power levels are studied for frequency bands below 6 GHz.

The correlation properties of the GBSM and the PSM have been studied in [1], [2] in terms of 4G long term evolution Advanced (LTE-A) standard.

The 3GPP also as ETSI gives out the standard of 5G channel modeling in [3] and the 5G channel modellings for many kinds of transceiving scenarios are surveyed in [4].

The derivation of the 3D MIMO channel space–time correlation function is for a fixed to mobile SIMO, MISO, MIMO system [5] in mmW frequency bands while [6] is deployed at 28 GHz local area suitable for MIMO system-level simulations based on exponential spatial autocorrelation of multipath component amplitudes.

In pre-coding and coding in mmW system, traditional MIMO solutions are made infeasible by the heavy reliance on a low hardware-complexity precoding solution [7] via formulating the problem of mmW precoder design.

In [8] new spatial correlation expressions for rectangular arrays of cross-polarized antennas with 3D and 2D channel models have been derived by showing the accuracy of decomposing 3D into elevation and azimuth components. For frequencies from 6 GHz to 100 GHz, authors in [9], [10] describe an initial 3D channel model includes: typical deployment scenarios for urban microcells (UMi) and urban macro-cells (UMa), indoor offices and shopping malls, derived from extensive measurements across a multitude of bands in terms of path loss, also as increased occurrence of blockage by delay spread, angular spread and multipath richness.

Of the LOS case, the overview of indoor channel properties for bands up to 100 GHz [11] was presented based on extensive measurements. The LOS probability, path loss, and clustering methodology [12] was compared between the 3GPP in urban environments (LOS and NLOS cases) and the massive amounts of real-world measured data to analyze that the NYUSIM is more accurate for realistic simulations than the other.

Of the 3GPP channel, the post processed BS Tx antenna patterns as well as power truncation, scaling

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for delay spread, angular spread and channel bandwidth in typical 8 x 8 Tx antenna patterns of 12 degrees half power beam-width [13] are investigated to study the serious quality of service issues in early mmWave deployments.

A path loss [14] is implemented by simulator based on the 3GPP to model and evaluate the performance of the physical layer techniques. The simulator considers four scenarios: RMa, UMa, UMi and InH, for both conditions: LoS and NLoS at 0.5-100 GHz. By using the PHP programming language host in a HTTP server, authors designed the estimation tools for link budget, maximum distance, minimum transmission power in such above environments.

The current work presents a studying of the spatial-temporal - frequency correlation characteristics in MIMO system caused by the models' structural difference or different parameter generation mechanisms. From that we can consider 5G channel model as system-level MIMO simulations. We also calculate the distance of the antenna elements in each base station (BS) and mobile station (MS) side in NLOS UMi, NLOS RMa and NLOS indoor cells at frequency band 6 GHz. Our results have been done by Monte Carlo simulator.

Our paper is structured as the followings: the summary of 5G channel modeling by the 3GPP specification is initiated in part 2. The properties of correlation of 5G channel modeling are computed in part 3. Part 4 is the simulation of correlation properties and the conclusion is given in part 5.

2. Summary of the 5G channel modelling in specification

We have Fig.1 showed a coordinate x, y, and z axes, with the spherical angles and the spherical unit vectors. This Cartesian coordinate system [3] has the zenith angle θ and the azimuth angle φ. The multiple BSs and MSs are used in Global Coordinate System (GCS) and an array antenna for a BS/MS is used in Local Coordinate System (LCS), which is used as a reference to define the is pattern and polarization vector far-field of each antenna element in an array.

The placement of an array within the GCS is occurred when translating between the GCS and the LCS by a sequence of rotations of the array with respect to the GCS. Therefore, it is necessary to map the vector fields of the array elements from the LCS to the GCS on which depends only on the orientation of the array. Thus, any arbitrary mechanical orientation of the array can be achieved by rotating the LCS with respect to the GCS.

We defined a GCS with coordinates (x, y, z, θ, ϕ) and unit vectors ($\hat{\theta}$, $\hat{\phi}$) and the LCS with "primed" coordinates $(x', y', z', \theta', \phi')$ and "primed" unit vectors ($\widehat{\theta'}$, $\widehat{\phi'}$). The arbitrary 3D-rotation of the LCS with respect to the GCS given by the angles α , β and γ, called the bearing angle, the down-tilt angle and the slant angle, respectively.

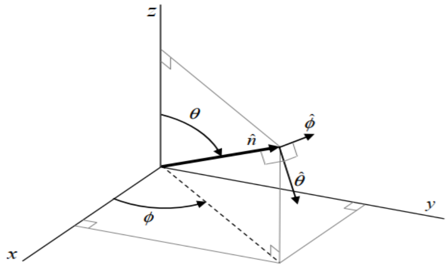

Fig. 1. The Cartesian of 5G channel modeling [3]

We set the $\dot{y}$ axis is the original y axis after the first rotation about z, and the $\ddot{x}$ axis is the original x axis after the first rotation about z and the second rotation about $\dot{y}$.

A first rotation of α about z sets the antenna bearing angle. The second rotation of β about $\dot{y}$ sets the antenna down-tilt angle. Finally, the third rotation of γ about $\ddot{x}$ sets the antenna slant angle. The orientation of the x, y, z axes after all three rotations can be denoted as $\ddot{x}$, $\ddot{y}$, $\ddot{z}$. The angular ψ now in charge of rotation to GCS is given as follow [3] and is illustrated in Fig.2:

$$\psi = \\ = \arg\begin{pmatrix} sin\gamma\cos\theta\sin(\phi-\alpha) + \\ +\cos\gamma(\cos\beta\sin\theta - \sin\beta\cos\theta\cos(\phi-\alpha)) \\ +j(sin\gamma\cos(\phi-\alpha) + \sin\beta\cos\gamma\sin(\phi-\alpha)) \end{pmatrix} \quad (1)$$

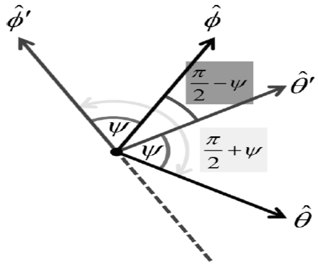

Fig. 2. Rotation of LCS w/ respect of GCS [3]

The simulators for 5G are defined for channel model calibration in Table 1 - Table 3 as [3]:

- UMi (Street canyon, open area) with O2O and O2I: the BSs are mounted below rooftop levels of surrounding buildings. UMi open area is intended to capture real-life scenarios in case of 50 to 100 m.

- Indoor: This scenario is intended to capture various typical indoor deployment scenarios, including office environments, and shopping malls. The BSs are mounted at a height of 2-3 m either on the ceilings or walls. The shopping malls are often 1-5 stories high and several floors.

- RMa: The rural deployment scenario focuses on larger and continuous coverage supporting high speed vehicle with noise-limited and/or interference limited, using macro transmission reception points.

Table 1. Parameters for UMi-street canyon [3]

Parameters		UMi -street canyon
Cell layout		Hexagonal grid, 19 micro sites, 3 sectors per site ISD= 200m
BS antenna height h_{BS}		10m
UT loca -tion	Outdoor/indoor	Outdoor and indoor
	LOS/ NLOS	LOS, NLOS
	Height h_{UT}	3D-UMi, TR36.873
Indoor UT ratio		80%
UT mobility (horizon)		3km/h
Min. BS-UT distance		10m
UT distribution		Uniform

Table 2. Parameters for indoor-office scenarios [3]

Parameters InH		open office	mixed office
Layout	Room size	$120m \times 50m \times 3m$	
	ISD	20m	
BS antenna height h_{BS}		3 m (ceiling)	
UT location	LOS/NLOS	LOS and NLOS	
	Height h_{UT}	1 m	
UT mobility (horizon)		3 km/h	
Min. BS - UT distance		0	
UT distribution (horizon)		Uniform	

Table 3. Parameters for RMa [3]

Parameters	RMa
Carrier Frequency	Up to 7GHz
BS height h_{BS}	35m
Layout	Hexagonal grid, 19 Macro sites, 3 sectors per site, ISD = 1732m or 5000m
UT height h_{UT}	1.5m
UT distribution	Uniform
Indoor/Outdoor	50% indoor and 50% in car
LOS/NLOS	LOS and NLOS
Min distance 2D	35m

3. The properties of the correlation functions of the 5G channel modelling in case of NLOS

The specifications of NLOS 5G simulators define the impulse respond function $h(,)$ of s BS antenna elements and u MS antenna elements [3].

$$h_{u,s}^{NLOS}(\tau,t)=\sum_{n=1}^{2}\sum_{i=1}^{3}\sum_{m\in R_i}h_{u,s,n,m}^{NLOS}(t)\delta(\tau-\tau_{n,i}) + \sum_{n=3}^{N}h_{u,s,n}^{NLOS}(t)\delta(\tau-\tau_n) \quad (2)$$

The transfer function $H(,)$ in frequency domain is the Fourier transform of $h(,)$ the channel impulse response and is calculated with τ_n is the delay of the n cluster.

$$H_{u,s}(f,t)=\sum_{n=1}^{N}h_{u,s}(\tau,t)\times e^{-j2\pi\tau_n f} \quad (3)$$

The spatial - temporal correlation function of 2×2 antenna system is calculated by the time average operator as:

$$\begin{aligned}&\rho(\Delta d_s,\Delta d_u,\Delta t,\Delta f=0)=\\&\langle H_{u_1,s_1}(f,t)\times H_{u_2,s_2}^{*}(f,t+\Delta t)\rangle=\\&=\sum_{n=1}^{N}\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\begin{pmatrix}e^{\frac{j2\pi(\hat{r}_{rx,n,m}^{T}\times\Delta\bar{d}_{rx,u})}{\lambda_0}}\\ \times\ e^{\frac{j2\pi(\hat{r}_{rx,n,m}^{T}\times\Delta\bar{d}_{tx,s})}{\lambda_0}}\\ \times\ e^{\frac{j2\pi(\hat{r}_{rx,n,m}^{T}\times\bar{v})}{\lambda_0}\Delta t}\end{pmatrix}\end{aligned} \quad (4)$$

The channel correlation is represented by the cross-correlation functions in case of NLOS. The spatial-temporal-frequency correlation functions of the transmitter and receiver 2×2 MIMO are calculated by the time average operation of the two transfer functions as equation (5). The $F_{rx,u,\theta}, F_{rx,u,\phi}$ are the radiation fields of the receive antenna element u with direction $\hat{\theta},\hat{\phi}$; $F_{tx,s,\theta}, F_{tx,s,\phi}$ are the radiation fields of transmit antenna element s with direction $\hat{\theta},\hat{\phi}$; $\hat{r}_{rx,n,m}^{T}$ is the spherical unit vector as the angle $\phi_{n,m,AOA}$ and $\theta_{n,m,ZOA}$; $\hat{r}_{tx,n,m}^{T}$ is the spherical unit vector as the angle $\phi_{n,m,AOD}$ and $\theta_{n,m,ZOD}$; $\bar{d}_{rx,u}$, $\bar{d}_{tx,s}$ are the location vectors of antenna element *u, s.*

Set $\Delta d_s=0,\Delta d_u=0$, the auto correlation (Temporal Correlation Function – TCF) is calculated as:

$$\rho(\Delta t)=\sum_{n=1}^{N}\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\exp\left(\frac{j2\pi(\hat{r}_{rx,n,m}^{T}\times\bar{v})}{\lambda_0}\Delta t\right) \quad (5)$$

Set $\Delta d_s=0,\Delta d_u=0$ and $\Delta t=0$, the auto correlation (Frequency Correlation Function–FCF) is shown as:

$$\rho(\Delta f)=\sum_{n=1}^{N}\sqrt{\frac{P_n}{M}}\exp\left(-j2\pi\tau_n\Delta f\right) \quad (6)$$

Set $\Delta t=\Delta f=0$ and $\Delta d_u=0$, the cross spatial correlation function of the channel at the transmitter is presented as:

$$\rho(\Delta d_s)=\sum_{n=1}^{N}\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}e^{\frac{j2\pi(\hat{r}_{tx,n,m}^{T}\times\Delta\bar{d}_{tx,s})}{\lambda_0}} \quad (7)$$

Similarity, the cross spatial correlation function at the receiver when $\Delta t=\Delta f=0$ and $\Delta d_s=0$ is as follows:

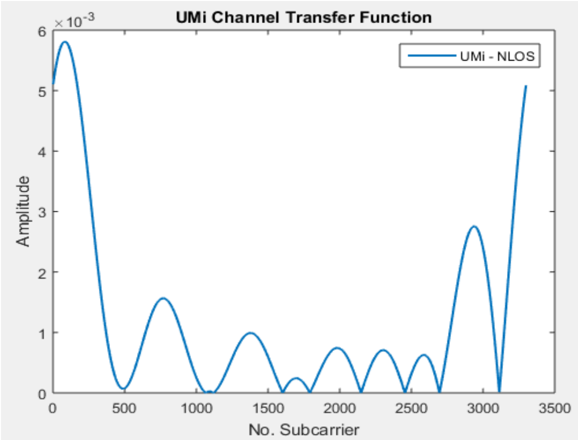

Fig. 3. The transfer function of UMi

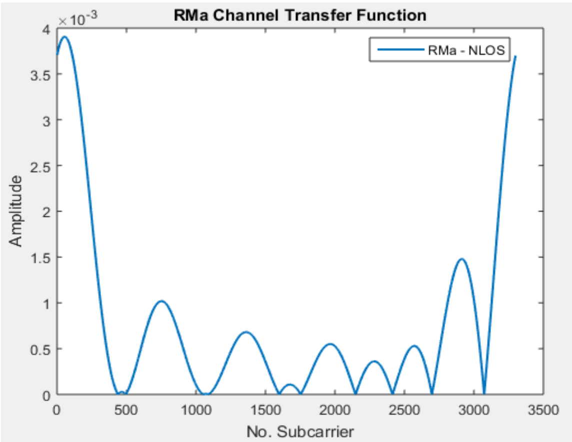

Fig. 4. The transfer function of RMa

$$\rho(\Delta d_u) = \sum_{n=1}^{N} \sqrt{\frac{P_n}{M}} \sum_{m=1}^{M} e^{\frac{j2\pi(\hat{r}_{rx,n,m}^{T} \times \Delta \bar{d}_{rx,u})}{\lambda_0}} \quad (8)$$

4. The simulation of correlation properties of 5G channel modeling

The graph of the channel's transfer function is obeyed the Rayleigh distribution. The transfer function is a probability procedure which depends on the frequency and time domains in NLOS case.

The shape of the element H_{11} of the channel in UMi environment in Fig.3 has the Rayleigh distribution, with the maximum point is .0058 at the eighth carrier-wave.

Fig.4 and Fig.5 are the graphs of the transfer function of the RMa and the InH in the case of NLOS. The amplitude in the RMa is smaller than the InH with the maximum point is .0039 at the fifth carrier-wave. The InH has the lowest path loss, the maximum point is .003 at the 61th carrier-wave.

The graphs of the spatial CCF built from the transfer function are present for 3 environments in case of NLOS in Fig.6. The spatial correlation's graph is at

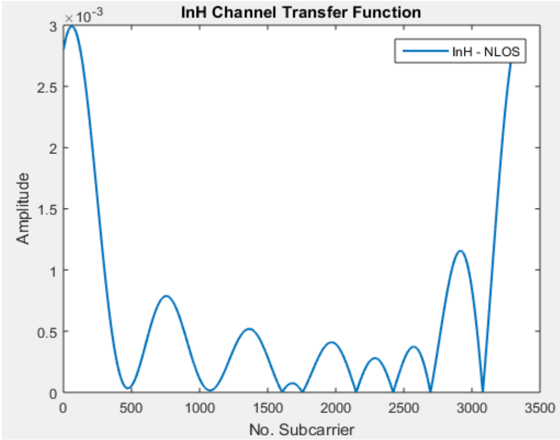

Fig. 5. The transfer function of InH scenario

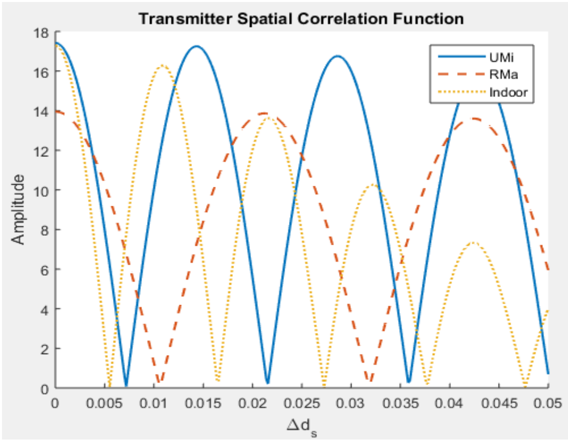

Fig. 6. The correlation properties in BS side

the transmitter BS's side when set $\Delta d_u = 0$. Those are having similar shape with different correlation values. The minimum amplitudes in three scenarios are in the range of the number of from 1600 to 1800 carrier-wave.

The minimum correlation values (MCV) have had by substituting the $\Delta d_u, \Delta d_s$ into equation (5) with $\Delta t = \Delta f = 0$ and are given in Table 4. At each environment, each of the MCV is regard to the obtained distance of the antenna elements in BS side.

Table 4. The min correlation value in BS side

UMi	MCV	0.128	0.148	0.104	
	Δd_s	0.006	0.022	0.036	
RMa	MCV	0.071	0.059		
	Δd_s	0.011	0.032		
In-door	MCV	0.061	0.072	0.062	0.056
	Δd_s	0.006	0.017	0.027	0.038

Table 5. The min correlation value in MS side

UMi	MCV	0.051	0.085		
	$\boldsymbol{\Delta d_s}$	0.011	0.029		
RMa	MCV	0.013	0.064		
	$\boldsymbol{\Delta d_s}$	0.009	0.028		
Indoor	MCV	0.109	0.083	0.017	0.09
	$\boldsymbol{\Delta d_s}$	0.006	0.018	0.028	0.039

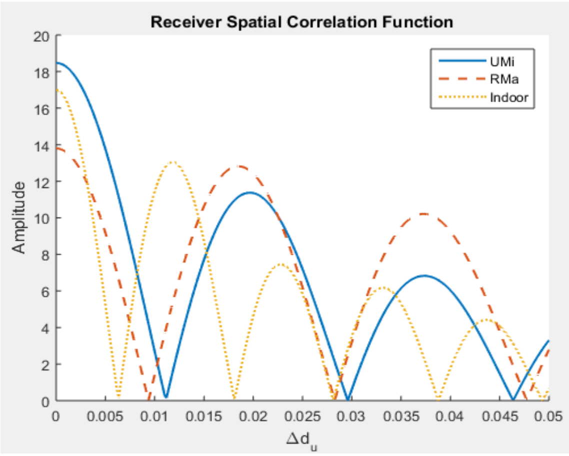

Fig. 7. The correlation properties in MS side

Fig.7 is the illustration of spatial correlation functions in MS side. The amplitude of the UMi is highest and the RMa is lowest.

As one can see, the distance of the antenna elements in the transmit side Δd_u has the minimum at the 0.005 - 0.01. The minimum correlation value of UMi, RMa and Indoor are 0.011, 0.0094 and 0.0063, respectively. In the range of $\Delta d_u = 0 - 0.04$, there are two minimum correlation values of the UMi and RMa, while the InH have four of that as in Table 5. That is, the InH scenario is much more changeable than the others.

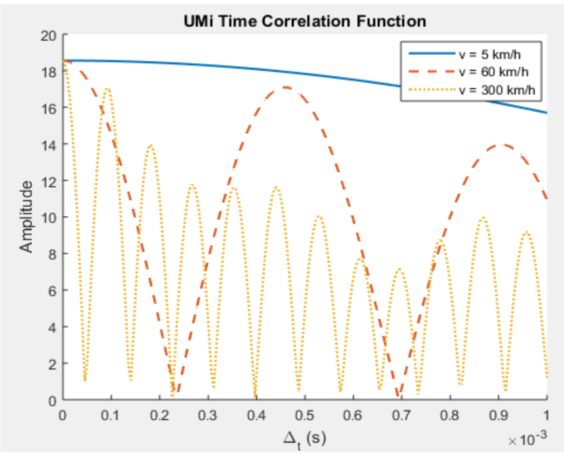

Fig. 8. The temporal ACF of UMi

The temporal ACF of UMi in Fig.8 depends on the velocity of the movement of the MS. In case of the high velocity of the MS, the variation of the signal is strong based on the Doppler spectrum theory. We have three divergent MS velocities such as 3km/h with walking pavement, 60 km/h with vehicles in the street, 300km/h with metro or high-speed rail. The high speed can be up to 500km/h as the 3GPP note. With pedestrian 5km/h, in the range of 10^{-3} s, the variation of the signal included the amplitude and phase is almost immutable. With vehicle moving 60km/h, in 10^{-3} s, the signal shifts greatly with 3 peaks. But the most altering signal is at the high-speed rail 300km/h, which makes 12 peaks in 10^{-3} s. Therefore, when the MS moving with high speed, the Doppler effect leads to changing of the coherence time.

The graph of the frequency ACF of UMi is in Fig.9 with the shape of probability distribution. In this scenario, the more increasing the Δf, the more decreasing the amplitude is.

In the bandwidth of 0 – 0.07 (GHz), the minimum correlation values of the frequency are at $\Delta f = \{0.0063, 0.0183, 0.0295, 0.0405, 0.0549, 0.0626, 0.0689\}$. Therefore, at each Δf the frequency correlation value is equal to 0. That is at each minimum frequency correlation point, the affection of the frequency at BS and MS side is negligible.

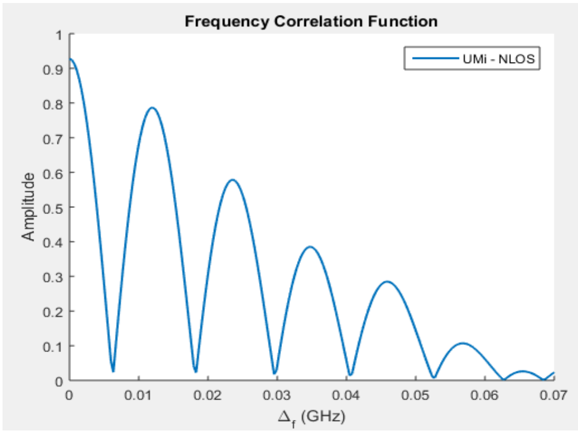

Fig. 9. The frequency ACF of UMi

5. Conclusion

We study the correlation properties of 5G channel modeling in MIMO 2 ×2 antenna system. The sets of temporal-spatial-frequency cross-correlation function are calculated and simulated in the scenarios of UMi, RMa and indoor NLOS cells at frequency band 6 GHz. Base on the built formulae, we determine the minimum correlation value at each MS, BS side. The MCVs depend on the distance elements of the antenna in each base station and mobile station side. We also identify the offset in time and frequency correlation functions to conclude that the signal is stable in each certain range. Based on the acquired correlation distinguishing, the simulations are at the system level of 5G channel modeling, leads to open more results to applied to uplink systems as well. We use Monte Carlo simulation method by Matlab programing. Our next research is estimating the system performance of the MIMO-OFDM using the LDPC coding based on 5G channel modeling above.

6. Acknowledgement

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