RIS Channel Modeling based on 3GPP Channel Model

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***Abstract*—In this paper, channel modeling of wireless communication systems including reconfigurable intelligent surface (RIS) is introduced. Based on the 3GPP channel model design, we propose a modified channel generation procedure with RIS.**

***Index Terms*—RIS, channel model, 3GPP**

I. Introduction

The reconfigurable intelligent surface (RIS) can perform functions such as reflection, penetration, and beamforming at low cost, so it is expected to be used in various fields such as indoor and outdoor coverage expansion, energy efficiency improvement, and sensing. For these reasons, it is emerging as one of the major candidate technologies for 6G communication, and various researches have been conducted recently. For various studies, a channel model in an environment including RIS is basically required, and many studies on wireless communication channel models including RIS are being conducted [1]– [5]. Meanwhile, 3GPP has developed a channel model for standardization of 5G mobile communication systems, and is conducting performance evaluation of various standard technologies based on the channel model [6]. In this paper, we propose a channel model design method including RIS based on the channel model design developed by 3GPP.

II. RIS Channel Modeling

Fig. 1 shows a wireless communication system model including RIS. In the figure, BS and UE represent a base station and a terminal, respectively. A channel from BS to UE can be written as follows.

$$H_{Tot} = H_{B,R} \times R(f_c, \Theta) \times H_{R,U} \quad (1)$$

where $H_{B,R}$ and $H_{R,U}$ indicate a channel between BS and RIS and a channel between RIS and UE, respectively. In additon, the following additional factors are required to generate the RIS channel model based on the 3GPP channel model. First, $R(f_c, \Theta)$ should be considered to generate the RIS channel model. $R(f_c, \Theta)$ consists of the different amplitude and phase

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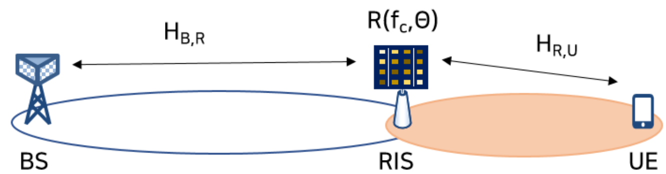

Fig. 1. System model with RIS.

responses of RIS according to frequency, and can be written as follows.

$$R(f_c, \Theta) = diag\left(\alpha(f_c, \theta_1)\beta_1 e^{j\theta_1}, \cdots, \alpha(f_c, \theta_N)\beta_N e^{j\theta_N}\right) \quad (2)$$

where $\alpha(f_c, \theta_n)$ is the different amplitude response of the RIS as a function of frequency and phase, β_n is the amplitude of the n-th RIS element, f_c is the center frequency, and $\Theta = [\theta_1, \cdots, \theta_N]$ is a matrix composed of RIS phase shift θ_n elements. Secondly, clusters of a channel between BS and RIS and a channel between BS and UE can be independently modeled. However, when UE is located relatively close to RIS, UE and RIS can share the same cluster. Thirdly, if the orientation of RIS is deterministic, the angle of arrival (AoA) and angle of departure (AoD) can be calculated by reflecting their location instead of calculating them randomly. In the 3GPP channel model, it is modeled randomly due to random orientation for UE. However, the orientation of RIS can be fixed as long as it is not mounted on a vehicle or a uncrewed aerial vehicle (UAV). The angle of incidence of RIS is calculated considering an arbitrary position of the cluster. Next, the scattering gain (antenna gain) according to the size of RIS can be reflected. Here, the scattering gain is the amount of power transmitted/received in direction of peak radiation relative to that of an isotropic antenna. Finally, pathloss modeling varies according to far-field, beamforming, and near-field broadcasting. In the case of near-field broadcasting, additive fading is reflected instead of multiplicative fading in pathloss.

As a result, RIS channel model can be generated by reflecting the above factors in the 3GPP channel model. Among the above factors, cluster and sub-lay sharing for channels between BS and RIS and between BS and UE should be applied only when the location of BS or UE is very close to the

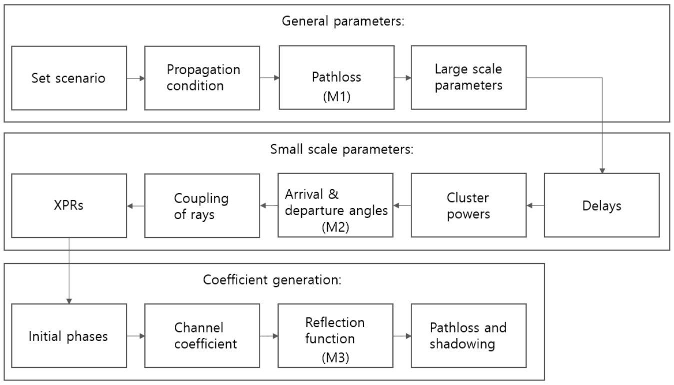

Fig. 2. Modified channel coefficient generation procedure based on 3GPP channel model.

RIS, and it is not expected to affect performance. In addition, the scattering gain according to the size of RIS may vary depending on the material of RIS, and research is required for a standardized RIS material. Therefore, when the remaining factors except for the above two factors are applied, the 3GPP channel generation procedure is modified as shown in Fig. 2. In the figure, modification steps based on the 3GPP channel generation procedure are M1, M2, and M3. In the M1, the pathloss can be written as follows.

$$PL_{Tot} = 10log_{10}(10^{PL_{B,R}/10} + 10^{PL_{R,U}/10})\ [dB] \tag{3}$$

in the case of broadcasting of RIS with $\{x \leq d_1$ or $d_2 \leq d_{NF}\}$. Here, d_1, d_2, and d_{NF} indicate the distance between BS and RIS, the distance between RIS and UE, and the near-field distance according to the size and frequency of RIS, respectively. For broadcasting, β_n is β for all n, and θ_n is either θ or $mod\left(\frac{2\pi}{\lambda}(\gamma_n^t - \gamma_n^{unit}), 2\pi\right)$. In the case of far-filed or beamforming, additive fading in (3) is replaced with multiplicative fading.

$$PL_{Tot} = 10log_{10}(10^{PL_{B,R}/10} \times 10^{PL_{R,U}/10})\ [dB] \tag{4}$$

in the case of beamforming of RIS or $\{d_{NF} < d_1$ and $d_2 \leq y\}$. Here, x and y depend on scenarios in the 3GPP channel model. For example, x and y are 10 m and 5 km respectively in the UMa scenario. In the M2, due to the deterministic orientation of RIS, the coordinates of the m-th scatterer in the n-th cluster in $H_{B,R}$ can be written as follows.

$$\begin{aligned} x^{n,m} &= x^B + a_c cos\theta_{n,m,ZOD} cos\phi_{n,m,AOD} \\ y^{n,m} &= y^B - a_c cos\theta_{n,m,ZOD} sin\phi_{n,m,AOD} \\ z^{n,m} &= z^B + a_c sin\theta_{n,m,ZOD} \end{aligned} \tag{5}$$

where $\theta_{n,m,ZOD}$ and $\phi_{n,m,AOD}$ indicate departure angles for elevation and azimuth, respectively. x^B, y^B, and z^B are the x, y, and z coordinates of the BS, respectively. The distance between all scatterers and BS is assumed to be a_c. If BS is in the yz plane and RIS is in the xz plane, the arrival angles of RIS with (5) can be written as follows.

$$\begin{aligned} \phi_{n,m,AOA} &= I_\phi tan^{-1}\frac{|x^R - x^{n,m}|}{|y^R - y^{n,m}|} \\ \theta_{n,m,ZOA} &= I_\theta sin^{-1}\frac{|z^R - z^{n,m}|}{b^{n,m}} \end{aligned} \tag{6}$$

where $I_\phi = sgn(x^R - x^{n,m})$, $I_\theta = sgn(z^{n,m} - z^R)$, $b^{n,m} = \left((x^R - x^{n,m})^2 + (y^R - y^{n,m})^2 + (z^R - z^{n,m})^2\right)^{1/2}$. If BS is in the yz plane and RIS is in the yz plane, $\phi_{n,m,AOA}$ can be written as follows.

$$\phi_{n,m,AOA} = I_\phi tan^{-1}\frac{|y^R - y^{n,m}|}{|x^R - x^{n,m}|} \tag{7}$$

where $I_\phi = sgn(y^{n,m} - y^R)$. After generating $H_{B,R}$ and $H_{R,U}$ according to the above procedure, M3 is added to reflect the different amplitude and phase responses of the RIS $R(f_c, \Theta)$ as described in (1).

III. Conclusions

In this paper, we proposed a procedure to generate a RIS channel model based on the 3GPP channel model. To generate the RIS channel model, three additional factors were reflected. The proposed RIS channel modeling is expected to be used for performance evaluation in wireless communication systems utilizing RIS. In future work, we will study the scattering gain reflecting the material characteristics of RIS.

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