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Performance analysis on reconfigurable intelligent surface and network-controlled repeater in 3GPP release-18

Key words: Reconfigurable intelligent surface (RIS); Network-controlled repeater (NCR); Standardization;

System-level simulation

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Motivation

1. As a candidate technique to achieve 6G, reconfigurable intelligent surface (RIS) has become popular in both academia and industry.
2. There are still many lessons to learn from former techniques to find a way to succeed in standardization.
3. As an evolved repeater, network-controlled repeater (NCR) has newly been standerlized in 3GPP R18. The comparison between RIS and NCR is worth researching.

Main idea

1. This paper considers the geometry of the planar array in the channel model.

2. This paper analyzes different noise characteristics for RIS and NCR in SNR performance simulation. Because of the reflecting ability, RIS does not introduce noise into the system. In contrast, NCR not only introduces but also amplifies the noise.

3. For better guidance in practice, this paper considers system-level simulation on the RIS and NCR systems.

Method

1. Technical comparison between RIS and NCR

Table 1 Technical comparison between RIS and NCR

Function	RIS	NCR
Basic function		
Access link indicator	Relevant to incident beam	Irrelevant to incident beam
Backhaul link indicator	Backhaul link beam probably different from the control link	Backhaul link beam can be the same as or different from the control link
Access link ON/OFF	When OFF, without phase control, mirror reflection	Default "OFF," no influence on the signal
Channel model	Small scale and near field to be researched	Current channel model
Enhanced function		
Energy saving	No amplifiers, strong need	Having amplifiers, no strong need
Channel estimation and feedback	New design under non-transparent channel	No requirement for terminal
Terminal measurement	Introducing terminal measurement, capable of assisting the base station and RIS in joint scheduling	No requirement for terminal

RIS: reconfigurable intelligent surface; NCR: network-controlled repeater

Method (Cont’d)

2. System model comparison

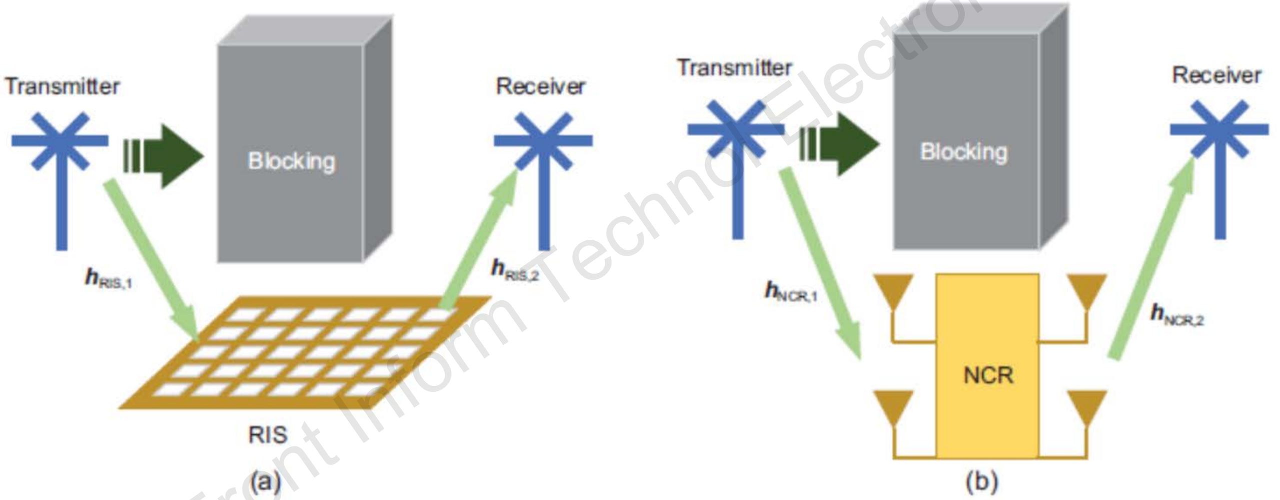
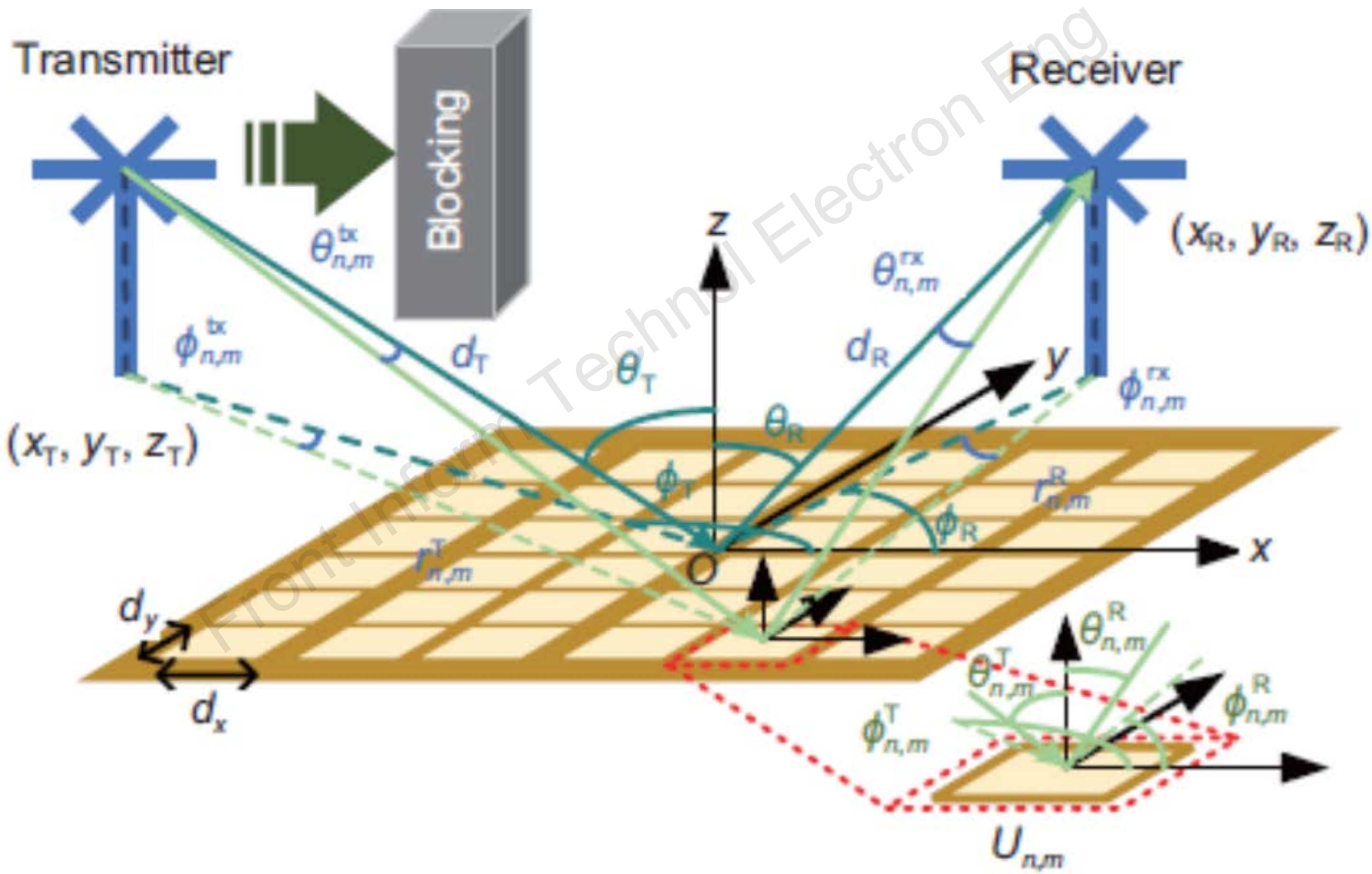


Fig. 1 Illustration of relay-assisted wireless communications without the direct path between the transmitter and the receiver: (a) RIS-assisted; (b) NCR-assisted (RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)

Method (Cont'd)

3. Antenna model



Method (Cont'd)

4. Based on the model, this paper theoretically analyzes the received power and SNR performances.

Received power comparison

$$\frac{P_{\mathrm{RIS}}^{\max}}{P_{\mathrm{NCR}}^{\max}}=\underbrace{\frac{B}{M_{\mathrm{NCR}}N_{\mathrm{NCR}}}}_{\text{NCR parameter}}\left(\frac{M_{\mathrm{RIS}}N_{\mathrm{RIS}}}{M_{\mathrm{NCR}}N_{\mathrm{NCR}}}\right)^2\left(\frac{A}{B}\right)^2$$

SNR comparison

$$\frac{\gamma_{\mathrm{RIS}}}{\gamma_{\mathrm{NCR}}}=\underbrace{\frac{B}{M_{\mathrm{NCR}}N_{\mathrm{NCR}}}}_{\text{NCR parameter}}\left(\frac{M_{\mathrm{RIS}}N_{\mathrm{RIS}}}{M_{\mathrm{NCR}}N_{\mathrm{NCR}}}\right)^2\left(\frac{A}{B}\right)^2 \cdot\left(1+\underbrace{\frac{G_{\mathrm{R}}\lambda^2}{16\pi^2 d_{\mathrm{R}}^2}\frac{\delta^2}{\delta_{\mathrm{R}}^2}}_{\text{system parameter}}\underbrace{GM_{\mathrm{NCR}}N_{\mathrm{NCR}}F(\theta_{\mathrm{R}},\phi_{\mathrm{R}})B}_{\text{NCR parameter}}\right)$$

Major results

Link-level comparison

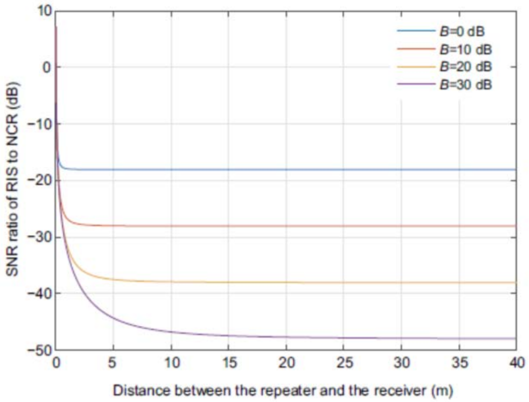


Fig. 3 SNR ratio of RIS to NCR with different NCR amplitudes B (SNR: signal-to-noise ratio; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater). References to color refer to the online version of this figure

Observation 1 The received power ratio of RIS to NCR is related to the number of antennas and the amplitude of NCR.

Observation 2 The noise introduced and amplified by the NCR can be ignored when the receiver is sufficiently far from the NCR, and the NCR suffers from severe decrease in SNR at downlink when the BS is near due to the constraint of relaying power.

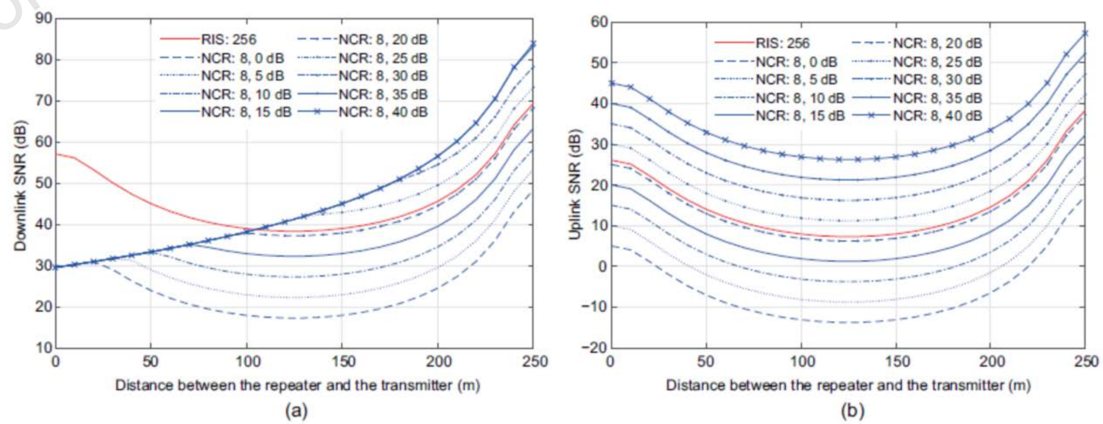


Fig. 4 SNR performance comparison of different repeater-assisted systems: (a) downlink; (b) uplink (SNR: signal-to-noise ratio; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)

Major results (Cont’d)

System-level performance analysis

Table 3 Simulation parameters

Parameter	Value
Height of the BS	25 m
Height of the MS	1.5 m
Height of the NCR	5 m
Height of the RIS	15 m
Transmitted power of the BS	43 dBm
Transmitted power of the NCR	30 dBm
Bandwidth	10 MHz
Number of antennas for the BS	8×16
Number of antennas for the MS	1×2
Number of elements per NCR	4×8
Number of elements per RIS	40×40/50×50
Number of NCRs (RISs) per cell	8
Number of MSs per cell	10
Antenna gain of the NCR (RIS)	5 dBi
Position of the NCR	0.95–1.00 cell radius
Position of the RIS	0.95–1.00 cell radius
Position of the MS	0.85–0.90 cell radius

BS: base station; MS: mobile station; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater

Noise

$$N_{\mathrm{MS}} = N_{\mathrm{BS-repeater}} + N_{\mathrm{repeater-MS}}$$

$$\begin{cases} N_{\mathrm{BS-repeater}} = -174\ \mathrm{dBm/Hz} + F_{\mathrm{repeater}} + B, \\ N_{\mathrm{repeater-MS}} = N_{\mathrm{BS-repeater}} + F_{\mathrm{repeater}} + F_{\mathrm{MS}} \\ \qquad -174\ \mathrm{dBm/Hz} + B \end{cases}$$

RSRP

$$P_{\mathrm{total}}^{\mathrm{RSRP}} = P_{\mathrm{BS-MS}}^{\mathrm{RSRP}} + P_{\mathrm{repeater-MS}}^{\mathrm{RSRP}}$$

SINR

$$\mathrm{SINR} = P_{\mathrm{total}}^{\mathrm{RSRP}} / (N_{\mathrm{MS}} + I_{\mathrm{BS-MS}} + I_{\mathrm{adjBS-adjrepeater-MS}} + I_{\mathrm{adjBS-repeater-MS}}),$$

$$G_{\mathrm{NCR}} = P_{\mathrm{T,NCR}} - P_{\mathrm{BS-NCR}}^{\mathrm{RSRP}} - N_{\mathrm{BS-NCR}} - I_{\mathrm{adjBS-NCR}},$$

Fixed gain relay

$$G_{\mathrm{NCR}} \leq P_{\mathrm{T,NCR}} - P_{\mathrm{BS-NCR}}^{\mathrm{RSRP}} - N_{\mathrm{BS-NCR}} - I_{\mathrm{adjBS-NCR}}.$$

Major results (Cont’d)

Performance in the FR1 band

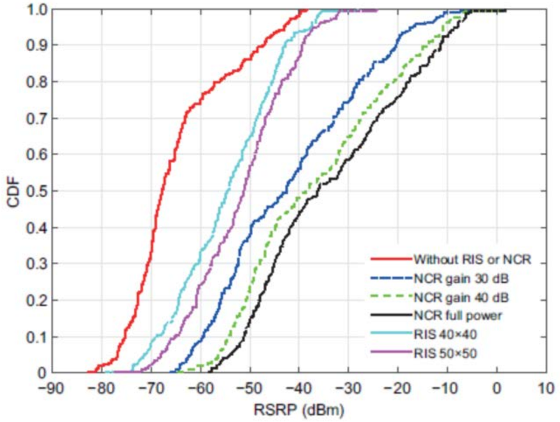


Fig. 5 **CDFs of the RSRP at 2.6 GHz (CDF: cumulative distribution function; RSRP: reference signal received power; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)**

Observation 3 In the FR1 band, NCR amplifies only the signal without beamforming. The RSRP of the NCR can surpass that of RIS in certain system parameter settings and the relative gain can be improved for the RIS when the number of array elements increases.

Observation 4 In the FR1 band, NCR amplifies only the signal without beamforming. The SINR performance of RIS always surpasses that of NCR because NCR amplifies noise and interference simultaneously.

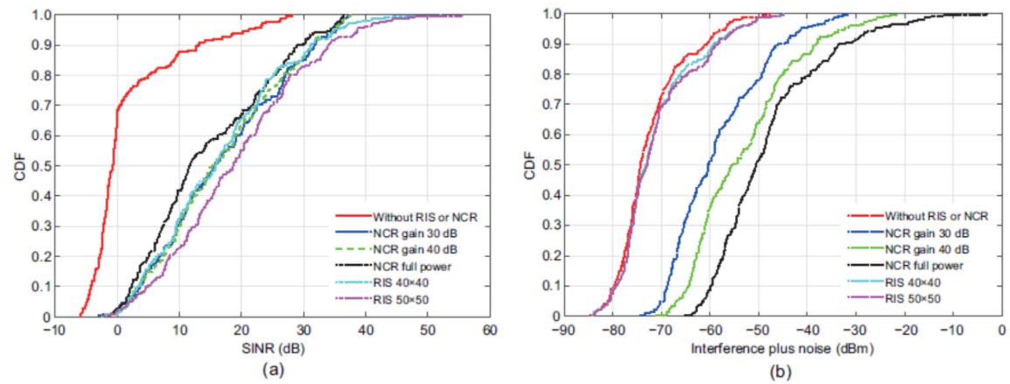


Fig. 6 **SINR performance comparison of different repeater-assisted systems, where the carrier frequency is 2.6 GHz: (a) CDFs of the SINR; (b) CDFs of the noise and interference (SINR: signal-to-interference-and-noise ratio; CDF: cumulative distribution function; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)**

Major results (Cont’d)

Performance in the FR2 band

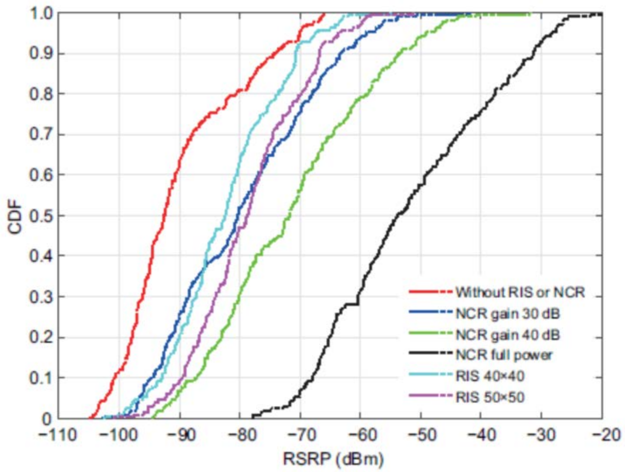


Fig. 7 CDFs of the RSRP at 26 GHz (CDF: cumulative distribution function; RSRP: reference signal received power; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)

Observation 5 In the FR2 band, RIS can be more accurate in terms of beam alignment compared to NCR.

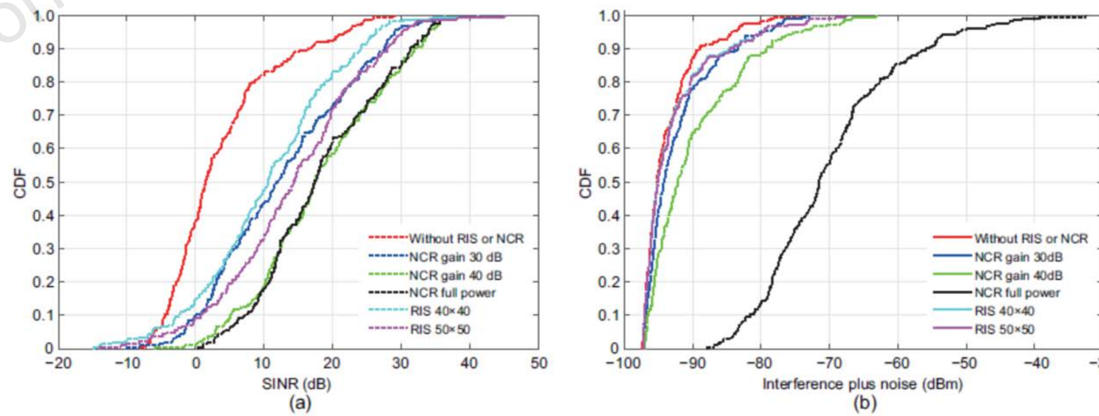


Fig. 8 SINR performance comparison of different repeater-assisted systems, where the carrier frequency is 26 GHz: (a) CDFs of the SINR; (b) CDFs of the noise and interference (SINR: signal-to-interference-and-noise ratio; CDF: cumulative distribution function; RIS: reconfigurable intelligent surface; NCR: network-controlled repeater)

Conclusions

1. In FR1, RIS can surpass NCR in terms of RSRP in certain system parameter settings. The SINR performance for RIS can be better than that of NCR.

2. In FR2, NCR can surpass RIS in terms of both RSRP and SINR in certain system parameter settings.

3. RIS is more flexible than NCR in context of deployment and applications. However, RIS needs more attention in the designing of the protocol architecture and the control methods..

Yiwei SUN received the B.S. and Ph.D. degrees from Beijing Institute of Technology, China, in 2016 and 2022, respectively. She is currently been with Future Research Lab, China Mobile Research Institute. Her research interests include reconfigurable intelligent surface and wireless communication techniques.

Yifei YUAN was with Alcatel-Lucent from 2000 to 2008. From 2008 to 2020, he was with ZTE Corporation as a technical director and chief engineer, responsible for standards & research of LTE-Advanced and 5G technologies. He joined the China Mobile Research Institute in 2020 as a Chief Expert, responsible for 6G. He has extensive publications, including nine books on LTE-Advanced and 5G. He has over 60 granted patents.