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| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access network;  Study on NR network-controlled repeaters;  (Release 18) | |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

[Editor’s Note: This clause is based on the text from the Objective parts in SID.]

The present document captures the findings from the study item “Study on NR Network-controlled Repeaters” [2].

The SI includes the study and identification of side control information (i.e., beamforming information, Timing information, information on UL-DL TDD configuration, ON-OFF information and power control information) for network-controlled repeaters and corresponding L1/L2 signaling (including its configuration) to carry the side control information. The scope of the study also includes the study on the aspects (i.e.,identification and authorization) of network-controlled repeater management

The study on NR network-controlled repeaters is to focus on the following scenarios and assumptions:

* Network-controlled repeaters are inband RF repeaters used for extension of network coverage on FR1 and FR2 bands, while during the study FR2 deployments may be prioritized for both outdoor and O2I scenarios.
* For only single hop stationary network-controlled repeaters
* Network-controlled repeaters are transparent to UEs
* Network-controlled repeater can maintain the gNB-repeater link and repeater-UE link simultaneously

NOTE1: Cost efficiency is a key consideration point for network-controlled repeaters.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP RP-213700: " New SI: Study on NR Network-controlled Repeaters ".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

**example:** text used to clarify abstract rules by applying them literally.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

<ABBREVIATION> <Expansion>

NCR Network-controlled repeater

NCR-MT NCR-Mobile termination

NCR-Fwd NCR-Forwarding

C-link Control link

# 4 Introduction

[Editor’s Note: This clause reuses the text from the Justification parts in SID.]

Coverage is a fundamental aspect of cellular network deployments. Mobile operators rely on different types of network nodes to offer blanket coverage in their deployments. Deployment of regular full-stack cells is one option but it may not be always possible (e.g., no availability of backhaul) or economically viable.

As a result, new types of network nodes have been considered to increase mobile operators’ flexibility for their network deployments. For example, Integrated Access and Backhaul (IAB) was introduced in Rel-16 and enhanced in Rel-17 as a new type of network node not requiring a wired backhaul. Another type of network node is the RF repeater which simply amplify-and-forward any signal that they receive. RF repeaters have seen a wide range of deployments in 2G, 3G and 4G to supplement the coverage provided by regular full-stack cells. In Rel-17, RAN4 specified RF and EMC requirements for such RF repeaters for NR targeting both FR1 and FR2.

While an RF repeater presents a cost effective means of extending network coverage, it has its limitations. An RF repeater simply does an amplify-and-forward operation without being able to take into account various factors that could improve performance. Such factors may include information on semi-static and/or dynamic downlink/uplink configuration, adaptive transmitter/receiver spatial beamforming, ON-OFF status, etc.

A network-controlled repeater is an enhancement over conventional RF repeaters with the capability to receive and process side control information from the network. Side control information could allow a network-controlled repeater to perform its amplify-and-forward operation in a more efficient manner. Potential benefits could include mitigation of unnecessary noise amplification, transmissions and receptions with better spatial directivity, and simplified network integration.

# 5 Modelling of Network-controlled repeater

[Editor’s Note: This clause intent to capture the conceptual model of network-controlled repeater.]

The Network-controlled repeater is modelled as Figure 5-1, which includes the NCR-MT and NCR-Fwd. The NCR-MT is defined as a function entity to communicate with a gNB via Control link (C-link) to enable the information exchanges (e.g. side control information at least for the control of NCR-Fwd). The C-link is based on NR Uu interface.

The NCR-Fwd is defined as a function entity to perform the amplify-and-forwarding of UL/DL RF signal between gNB and UE via backhaul link and access link. The behavior of the NCR-Fwd will be controlled according to the received side control information from gNB.

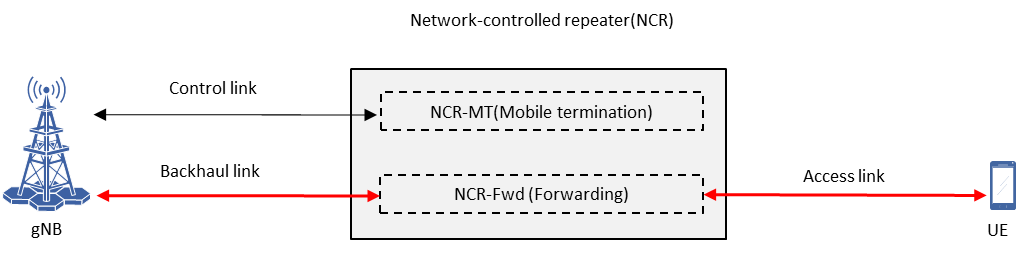


Figure 5-1: Conceptual model of Network-controlled repeater

Additionally, at least one of the NCR-MT’s carrier(s) should be within the set of carriers forwarded by the NCR-Fwd in same frequency range. And the NCR-MT and NCR-Fwd operating in the same carrier is prioritized for the study.

As baseline, same large-scale properties of the channel, i.e., channel properties in Type-A and Type-D (if applicable), are expected to be experienced by C-link and backhaul link (at least when the NCR-MT and NCR-Fwd operating in same carrier).

For the transmission/reception of C-link and backhaul link by NCR,

* The DL of C-link and DL of backhaul link can be performed simultaneously or in TDM way.
* The UL of C-link and UL of backhaul link can be performed in TDM way

The multiplexing is under the control of gNB with consideration for NCR capability and simultaneous transmission of the UL of C-link and UL of backhaul link is also subject to NCR’s capability

# 6 Side control information

[Editor’s Note: This clause includes the progress for each side control information, which will be captured in sub-clause. Potential analysis for cost for each information can be captured based on the agreement.]

## 6.1 Beam information

For the backhaul link and C-link, both fixed beam and adaptive beam can be considered at NCR for both C-link and backhaul-link, where the fixed beam refers to the case that beam at NCR for both C-link and backhaul-link cannot be changed.

As baseline, the same TCI states as C-link are assumed for beam at NCR-Fwd for backhaul link if the NCR-MT’s carrier(s) is within the set of carriers forwarded by the NCR-Fwd (FFS: additional indication from gNB to determine the beam at NCR-Fwd for backhaul link or implicit determination of the beam at NCR-Fwd for backhaul link).

For the access link, at least for FR2, beam information is beneficial and recommended as the side control information for network-controlled repeater to control the behaviour of NCR at least for access link.

In the access link beam indication, an access link beam can be indicated by

* Option 1: A beam index
* Option 2: An index of a source RS (e.g. a TCI-like indicator)

The time domain resource corresponding to an access link beam is explicitly determined based on the explicitly indicated the time domain resources per beam indication, which is to indicate one or multiple beams in single beam indication. Different parameters may be indicated for semi-static or dynamic beam indication.

Both the dynamic indication and semi-static indication can be considered for the beam of access link for NCR-Fwd. (FFS: the details of each indication; FFS: the maximum number of beams configured for NCR-Fwd access link)

The same assumption of the beam correspondence is applied for DL/UL of the backhaul link at NCR-Fwd as the DL/UL of the C-link at NCR-MT. The beam correspondence is assumed for the DL/UL of the access link at NCR-Fwd.

## 6.2 Timing information

For the timing of NCR, the following assumption is considered as baseline:

* The DL receiving timing of the NCR-Fwd is aligned with the DL receiving timing of the NCR-MT.
* The UL transmitting timing of the NCR-Fwd is aligned with the UL transmitting timing of the NCR-MT.
* The DL transmitting timing of the NCR-Fwd is delayed after the DL receiving timing of the NCR-MT (or the NCR-Fwd) by the internal delay;
* The UL receiving timing of the NCR-Fwd is advanced before the UL transmitting timing of the NCR-MT (or the NCR-Fwd) by the internal delay.

It’s conclude that legacy UE mechanism is sufficient to achieve DL/UL timing for NCR-MT

## 6.3 Information on UL-DL TDD configuration

For the TDD UL/DL configuration of network controller repeater, at least semi-static TDD UL/DL configuration is needed for network-controlled repeater for links including C-link, backhaul link and access link(FFS: handling of flexible symbols)

The same TDD UL/DL configuration is always assumed for backhaul link and access link. Additional, the same TDD UL/DL configuration is assumed for C-link and backhaul link and access link if NCR-MT and NCR-Fwd are in the same frequency band.

## 6.4 ON-OFF information

ON-OFF information is beneficial and recommended for network-controlled repeater to control the behaviour of NCR-Fwd. (FFS: Detailed mechanism of ON-OFF indication and determination FFS: explicit indication or implicit indication of ON-OFF information)

The following options can be considered to indicate the ON-OFF information from gNB to NCR for controlling the behaviour of NCR-Fwd:

* Option 1: Explicit indication with on-off state (e.g., via dynamic or semi-static signalling) or on-off pattern (e.g., periodic/semi-static ON-OFF pattern or new DRX-like pattern for ON-OFF)
* Option 2: Implicit indication via the signalling for other information (e.g., beam, DL/UL configuration, or PC information)
  + Note: This example does not imply that PC information is necessary or not.
* Other solutions (e.g., potential combination of explicit and implication solution) can be further discussed.

## 6.5 Power control information

The controlling of the amplifying gain of NCR-Fwd is considered to enable the power control of NCR-Fwd if PC is recommended as side control information for NCR in Rel-18 (FFS: Controlling of the transmission power of NCR-Fwd)

# 7 L1/L2 signalling for side control information

## 7.1 Signalling for side control information

[Editor’s Note: This clause includes the candidate signalling for each side control information including the required enhancement on other aspects, which will be captured in sub-clause.]

### 7.1.1 Signalling for beam information

From the perspective of signaling design, following mechanisms can be considered for the access link beamforming of the NCR-Fwd.

* Option #2-1: Dynamic beam indication only
* Option #2-2: Semi-static beam indication only
* Option #2-3: Dynamic beam indication and semi-static beam indication

The time at which the NCR applies an access link beam indication should be considered.

As for the time-domain granularity of the access link beam indication,one or bothofthe following options canbe considered (FFS: The details of indication signaling):

* Option 1: slot-level
* Option 2: symbol-level

### 7.1.2 Signalling for timing information

For the signaling of the side control information of timing to align transmission / reception boundaries, new signaling may be unnecessary (FFS: the impact of internal delay).

### 7.1.3 Signalling for UL-DL TDD configuration

For the signaling of information on UL-DL TDD configuration, if the NCR-MT can acquire the TDD configuration as legacy UEs or from the OAM, new signaling may not be necessary. The same TDD UL/DL configuration is assumed for C-link and backhaul link and access link if the NCR-MT and the NCR-Fwd are in the same frequency band. (FFS: Other cases where new signaling may be necessary.)

### Signalling for ON-OFF information

For indication of NCR-Fwd ON-OFF for efficient interference management and improved energy efficiency, both dynamic and semi-static indication can be considered. (FFS: RAN1 to consider whether/how to handle the forwarding of broadcast and cell-specific signals/channels.)

### 7.1.5 Signalling for power control information

## 7.2 Configuration of signalling

For the configuration of signalling, the NCR-MT can obtain the necessary configuration for receiving the L1/L2 signaling of the side control information.

* Option 1: The necessary configuration is from RRC.
* Option 2: The necessary configuration is from OAM or hard-coded.
* Option 3: The necessary configuration is partially configured by RRC and partially configured by OAM or hard-coded.

The necessary configurations from RRC and/or OAM(or hard-coded) contain:

* The configurations of PHY channels to carry the L1/L2 signaling including
  + The configurations for receiving PDCCH and PDSCH.
  + The configurations for transmitting PUCCH, if needed.
  + The configurations for transmitting PUSCH, if needed.
* The configurations of L1/L2 signaling including
  + The configurations for DCI.
  + The configurations for UCI, if needed.
  + The configurations for MAC CE, if needed.

For the parameters in the necessary configurations for L1/L2 signaling, the existing parameters for PDCCH, PDSCH, PUCCH, PUSCH, DCI, UCI and MAC CE in Rel-17 are the baseline for further discussion.

# 8 Repeater management

[Editor’s Note: This clause includes the aspect related to repeater management (i.e., identification and authorization) including the required assistance on other aspects.]

## 8.1 Solution on Repeater management

## 8.2 Specification impacts

[Editor’s Note: This clause includes the identified specification impacts for each solution based on the inputs from RAN2 and RAN3, it will be captured in sub-clause.]

# 9 Performance evaluation

[Editor’s Note: This clause mainly includes the potential simulation results for each side control information based on the agreement.]

For the side control information, the performance have been evaluated in the submitted contribution with following observations:

* For the beam information used to control the beam of access link:
* [R1-2203237] shows that the NCRs with beam information can improve the SINR performance, especially for the UE at 5%-tile, 50%-tile of CDF. Meanwhile, compared to the legacy RF repeater, the additional interference can be mitigated for the UE above 95%-tile of CDFs.
* [R1-2203578] shows that when the RU beam is fixed to set towards the cell edge, the SINR performance of the UEs is improved compared with the case when there is no repeater. Especially for the cell edge UE, SINR gain is 2.3 dB for the 10% UE with the worst SINR. When the RU beam is set dynamically towards the serving UE, the SINR performance of the UEs is further improved compared with the case of the fixed RU beam. Especially for the cell edge UE, SINR gain is about 6.3 dB for the 10% UE with the worst SINR.
* [R1-2203921] shows that by introducing repeaters applying beamforming, 2.34 dB, 6.15 dB, and 6.53 dB gain can be achieved at 5%-tile, 50%-tile, and 95%-tile CDFs of the SINR compared to the NR system without repeaters, respectively. In addition, 2.03 dB, 5.18 dB, and 6.53 dB gains at 5%-tile, 50%-tile, and 95%-tile CDFs of the SINR can be achieved compared to the NR system with legacy repeaters, respectively.
* [R1-2204653] shows that performance gain on SINR can be achieved by introducing semi-static repeater gain/power configuration, and additional performance gain can be achieved by introducing dynamic repeater gain/power configuration. More than 5 dB gain can be further achieved by using large SCI payload for beam control for large repeater-RU antenna configuration.
* [R1-2205047] shows that Adaptive access-link (UE-side) beamforming will offer significant performance gain by providing a larger beamforming gain and reducing the interference (due to use of narrower beams), e.g., the median SINR can improve by 11dB.
* [R1-2206927] The NCR with beamforming has a valid SINR gains over gNB only and legacy RF repeater. Compared with gNB only, NCR has a SINR improvement about 1.42 dB, 1.44 dB, and 3.06 dB at 5%-tile, 50%-tile, and 95%-tile CDF. NCR could improve the coverage and SINR of the UE compared with gNB only and deployment with legacy RF repeaters.
* [R1-2206055] When the NCR beam is set adaptively towards the serving UE, the SINR performance of the UEs is further improved compared with the case of the fixed RU beam. Especially for the cell edge UE, UL SINR gain is about 6.3 dB for the 10% UE with the worst SINR, DL SINR gain is 8 dB for the 10% UE with the worst SINR.
* [R1-2206018] shows that with indicated beam information, the SINR performance on FR1 in the O2I scenario have been improved with the gain around 5dB @5%tile of CDF and 2dB @50% tile of CDF after the deployment of NCR, and NCR provides obvious SINR improvement compared to legacy RF repeater in all cases. NCRs with beam information can also improve the SINR performance on FR1 in realistic outdoor scenario with around 7 dB gain as the lowest value of CDF and 3dB gain @5%tile of CDF.
* [R1-2206957] shows that a small payload of SCI (e.g. 4 bits) can provide SINR gains for more than 80% of indoor UEs. And the side effect from repeater at FR1 can be resolved by a proper CSI feedback and scheduling in the practical environments.
* [R1-2205875] Based on evaluation methodology defined for NR coverage enhancements [TR 38.830], the performance of NCR is evaluated for FR1 assuming target data rates of 10 Mbps for downlink and 1 Mbps for uplink, target ISD is 500m, gNB EIRP 70 dBm, UE EIRP 26 dBm, NCR with DL EIRP 32 dBm and gain 65 dB. The achieved ISD by gNB only can be up to m for both uplink and downlink. The target coverage for FR1 can be achieved with BS only.



* For the ON-OFF information used to control the ON-OFF behaviour of NCR-Fwd:
* [R1-2203237] shows that NCRs with ON-OFF information can mitigate the interference for high SINR UEs while maintain the performance of low SINR UEs, and also ON-OFF information can provide efficient interference management in FR1.
* [R1-2203578] shows that about 9.8dB gain can be achieved for the 10% tile UEs on the SINR performance after introducing ON-OFF indication.
* [R1-2203921] shows that additional gain is observed for the repeater by both applying beamforming and on/off management compare to the NR system with the repeater only applying beamforming.
* [R1-2205047] shows that about 2 dB gains on median SINR can be achieved by introducing dynamic on-off information.
* For the power control information used to control the behaviour of NCR-Fwd for the DL of access link and/or UL of backhaul link:
* [R1-2203133] shows that for the uplink transmission via NCR, a fixed NCR amplifying gain may lead to interference to the gNB or NCR UL coverage loss. For the downlink transmission via NCR, a fixed NCR amplifying gain may lead to NCR RU saturation or NCR DL coverage loss.
* [R1-2203578] shows that the optimal system performance can be achieved when repeater’s gain is set to a proper value.
* [R1-2204653] shows that dynamic repeater gain/power control can provide additional SINR gain over semi-static repeater gain/power configuration.
* [R1-2204642] mentions that the gain control is needed for self-interference management due to repeater oscillation.

# 10 Conclusion

The following aspects are recommended ***to be specified*** as part of Rel-18 NCR WI from RAN1’s perspective:

* For beam information as side control information
  + The beam index is used to indicate the access link beam of NCR-Fwd [in both semi-static and dynamic way].
  + The time domain resource corresponding to an access link beam is explicitly determined based on the explicitly indicated the time domain resources per beam indication, which is to indicate one or multiple beams in single beam indication
* For ON-OFF information as side control information
  + Both dynamic and semi-static indication is used to indicate ON-OFF state of NCR-Fwd
  + The indication can be in explicit or implicit way
* For UL-DL TDD configuration
  + [Semi-static configuration is supported for NCR without specification impact.]
  + For the NCR’s behaviour over flexible symbols based on semi-static configuration, two options are studies and down-selection is expected in normative phase.
* For Timing information
  + [The value of internal delay of NCR-Fwd is defined as NCR’s capability.]
* For power control information
* For the configuration of signalling:
  + Three options for signalling configuration are studies and down-selection is expected in normative phase

Annex <A>:  
<Annex title for a Technical Report>

# A.1 Heading levels in an annex

Annex <B>:  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2022-05 | RAN1#109e | R1-2205231 |  |  |  | TR Skeleton | V0.0.0 |
| 2022-05 | RAN1#109e | R1-2205496 |  |  |  | Capture the agreement in RAN1#109e | V0.1.0 |