WHITE PAPER

Boost IoT with 5G NR RedCap

Optimized design meets use case requirements
for low cost and power consumption

KEYSIGHT

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RedCap: 5G NR to Support IoT Growth

The adoption of 5G New Radio (NR) has grown rapidly since its first commercial launch in 2019, bringing a significant boost in data rates to mobile devices. As of February 2022, nearly 200 operators in more than 60 countries had launched 5G mobile services. With the 3rd Generation Partnership Project's (3GPP) Release 17, 5G NR expands its reach to new users with diverse requirements.

While applications such as Time-Sensitive Networks (TSNs) require very low latency and a robust downlink and uplink, many Internet of Things (IoT) applications have lower capacity and latency requirements, but have stringent cost and power consumption constraints.

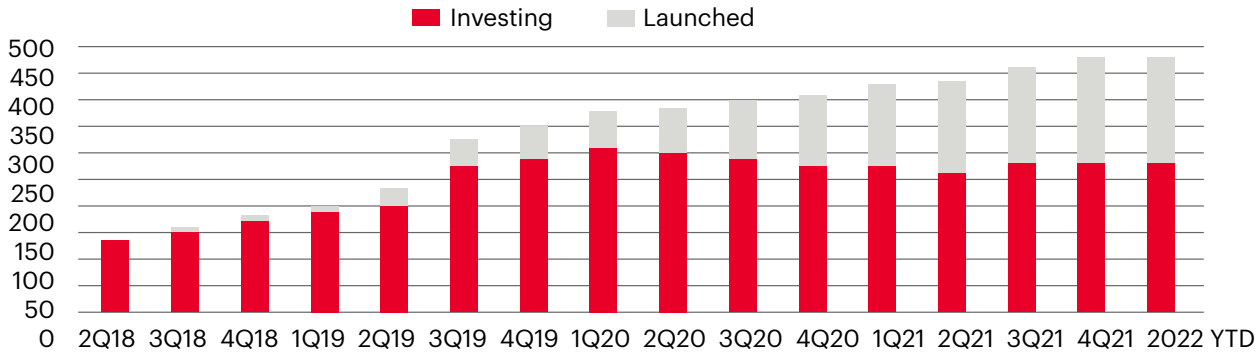


Figure 1. Count of operators investing in 5G and operating commercial 5G networks
Source GSA-5G Market Update (February 2022)

This white paper looks back at the first cellular technologies that supported IoT. It examines 5G NR reduced capability (RedCap) devices, a category of user equipment (UE) that requires more capacity than LTE-based technologies (Cat-M or NB-IoT) provide and supports low cost and power consumption. It includes a review of the new parameters and the most relevant changes introduced in 3GPP R17 Layer 1, Layer 2, and Layer 3 procedures to support new RedCap devices.

IoT device shipments are on track to grow at double-digit rates through the 2020s. 5G NR RedCap can succeed if it adequately meets the coverage, cost, and power consumption requirements of IoT applications while operating on 5G networks, enabling operators to support all services with a single cellular radio access technology (RAT).

Evolution of Cellular IoT

Mobile networks have evolved from supporting strictly voice services to supporting voice and data connectivity services. This development enabled cellular networks to incorporate electronic devices deployed in the field to monitor conditions and send data remotely, reducing the cost of operating certain types of sensors and equipment by requiring fewer on-site visits. But this change required the creation of globally accepted interoperability standards. These standards, which define the protocols and RF interfaces, seek to minimize the incremental cost of devices to maximize the cost benefit of remote wireless access.

3GPP first included technologies for these types of devices in Release 13 and added subsequent enhancements up to Release 16. The 3GPP standards defined three categories of technologies as cellular IoT (C-IoT):

- extended coverage GSM IoT (EC-GSM-IoT) based on 2G, aiming to leverage the existing networks and subscriber base
- LTE for machine-type communications (LTE-M), compatible with regular LTE
- Narrowband IoT (NB-IoT), which brought new device specifications to further optimize power consumption and coverage even in tough environments such as underground installations

Table 1. Release 13 IoT technology capabilities

	NB-IoT (Rel-13)	LTE-M (Rel-12 / 13)	EC-GSM (Rel-13)
Range max. coupling loss	< 15 km 164 dB	< 11 km 144 dB	< 15 km 164 dB
Spectrum bandwidth	Licensed 700 – 900 MHz 200 kHz or shared	Licensed 700 – 900 MHz 1.4 MHz or shared	Licensed 800 – 900 MHz 2.4 MHz or shared
Data rate	< 100 kbps	< 1 Mbps	
Voice service	No	Yes	Yes
Battery life	> 10 years	> 10 years	> 10 years

Compared with competing technologies, C-IoT can offer enhanced quality of service because it uses regulated spectrum and support from mobile network operators. It achieves global compatibility by adhering to 3GPP standards and certification organizations such as the Global Certification Forum (GCF) and PCS Type Certification Review Board (PTCRB).

How RedCap Fits into 5G NR Use Cases

Enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC), and massive machine-type communications (mMTC) were the foundational goals of 5G NR. More recently, 3GPP added TSN to the list.

The concept of RedCap is to build user equipment (UE) that can benefit from the scale of 5G NR deployments but leverage fewer 5G NR capabilities for an optimum balance of features versus cost and power consumption. 3GPP created a study item to research support for reduced-capability NR devices. The study item ultimately became a 3GPP work item, with RedCap introduced in Release 17.

URLLC, mMTC, and TSN cover IoT connectivity with high-bandwidth and low-latency requirements, such as manufacturing line robotics and drones. But they do not necessarily cover connectivity for sensors, actuators, and other IoT equipment with lower performance requirements that are typically cost- or form-factor constrained. These devices may send asynchronous information in small packets but need radical cost optimization in initial purchase and operational maintenance for which battery life duration is critical.

Apart from "smart" industries, 3GPP also included two other RedCap use cases in Release 17 specifications: surveillance devices and wearables that can gather and relay health and wellness information.

First RedCap Release in R17

Figure 2 lists the main areas of interest for RedCap and the major initiatives undertaken in Release 17:

Use case	Cost-reduction strategies	Low power consumption enhancements
• Industrial sensors • Wearables • Surveillance	• Reduced Tx / Rx and MIMO • Reduced bandwidth • Half-duplex and reduced antenna gain	• Relaxed DL and RRM monitoring • Extended disconnect receiver times • Small data transmission

Figure 2. 5G NR RedCap goals and related implementation strategies

The initial use cases under analysis show low data throughput and latency requirements compared with other 5G NR devices that will support eMBB (Table 2).

Table 2. RedCap's first use cases, data rate, and latency requirements

Use case	Data rate (max)	End-to-end latency	Service availability
Wireless industry sensor	2 Mbps	< 100 ms	99.99%
Wearables	25 Mbps		
Surveillance	150 Mbps (DL), 50 Mbps (UL)	< 500 ms	99 – 99.9%

Source: 3GPP TR 38.875

Release 17 introduces the necessary changes to the 5G specifications to support devices with reduced capabilities. Examples include the following:

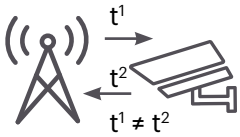
- the use of reduced bandwidth of 20 MHz with implications in the bandwidth part (BWP) configurations both in downlink (DL) and uplink (UL)
- support for devices with a single transmitter and receiver branch
- support for one DL layer and one UL layer

The initial deployments of RedCap devices will be on a single connection, which NR can support with frequency range 1 (FR1) and frequency range 2 (FR2) standalone deployments.

Release 17 also supports half-duplex frequency division duplex (FDD), a transmission mode that can significantly impact device cost. There are, however, some drawbacks. With half-duplex FDD, the device will not detect scheduling information for DL and UL in the same set of symbols. The device cannot monitor DL messages while configured in UL mode and will not be able to send uplink control information while monitoring DL. In case of conflict, the device can decide what to do based on its implementation, but it will not be able to do both transmission and reception simultaneously.

The simpler specs of RedCap allow device makers to remove components, reducing the final device cost. For a successful IoT product launch, every cent counts. Table 3 summarizes key cost-reduction simplifications in the initial RedCap devices and the potential benefits and trade-offs.

Table 3. Benefits and trade-offs of RedCap cost-reduction strategies

	What	Benefits	Trade-off
	Reduced number of Tx and Rx with support for maximum DL 2x2 and UL SISO only	Strong cost reduction	Coverage and maximum data rates
	Reduced bandwidth of 20 MHz (FR1) [1]	Strong cost reduction	Coverage and maximum data rates
	Half-duplex FDD instead of full-duplex FDD	Moderate cost reduction	Increased scheduling complexity as RedCap half duplex device will not monitor DL messages while communicating in UL

1. 100 MHz in FR2, although the first deployment will more likely be in FR1

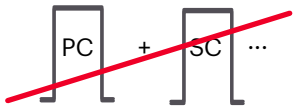
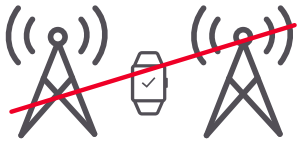
Reduced complexity and power consumption

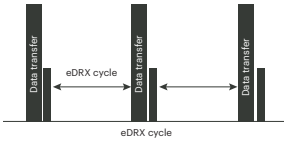
So far, we have examined RedCap and how it can reduce device costs by relaxing some NR-related specs. The next step is how to reduce device complexity, which can enable size reductions to fit the RF components in the final form factor of devices such as smart glasses. Release 17 requirements for RedCap devices include enhancements such as the use of single connectivity and only selected power classes.

Finally, Release 17 also relaxes some requirements in a few areas to reduce power consumption. Since RedCap devices are typically either static or moving slowly, reducing network monitoring activities can produce significant power savings without impacting the device value for some use cases.

Table 4 summarizes the key simplifications implemented in the initial RedCap devices and their potential benefits and trade-offs.

Table 4. Benefits and trade-offs of RedCap simplifications

	What	Benefit	Trade-offs
	Single carrier, with no support for carrier aggregation scenarios	Simplified baseband development	Reduced maximum throughput
	Single connectivity, NR standalone only	Reduced RF module size and cost	Requires 5G standalone coverage and cannot connect to 5G networks using LTE as an anchor; also, no support for fallback to other RATs, which reduces coverage
	Power Class 3	Optimized power consumption reduces built-in battery size	Coverage

	What	Benefits	Trade-off
	Reduced network monitoring (PDCCH) with fewer blind decodes (BD) and control channel element limits	Power savings	Latency, if PDCCH blocking probability increases due to fewer BDs; can also impact UE scheduling flexibility
	Longer extended discontinuous reception (eDRX) cycle during RRC disconnect or idle state, device will not monitor PDCCH	Power savings	Mobility performance decrease
	Radio resource management (RRM) relaxation for stations devices that are not at cell edge (detected by RRM relaxation triggers criteria)	Power savings	None for the stationary device use case, but may not be applicable for devices in motion beyond a certain speed as handover and radio link failures may increase
	Small data transmission: R17 allows the UE to transmit data while in RRC inactive state	Power savings	

Key RedCap Parameters in R17

For the network, the primary impact from the introduction of RedCap devices is the need to adapt to their specific features during the random-access channel (RACH) process and when the device stays connected. New information elements (IEs) handle those processes, as summarized in Table 5.

Table 5. Selection of R17 information elements relevant to RedCap device operation

Parameter	Included in	How it is used
cellBarredRedCap-r17	SIB1	"Barred" indicates the RedCap UE cannot camp in the cell and needs to start the radio resource control (RRC) procedure to camp in another cell "NotBarred" indicates the RedCap UE can proceed with the RRC procedure in that cell
intraFreqReselection RedCap-r17	SIB1	This parameter is necessary for RedCap UE support; if not present, the cell will be barred
halfDuplexRedCapAllowed	SIB1	If not present, then the UE shall consider the cell barred and consider re-selection to other cells on the same frequency
initialDownlinkBWP-RedCap in DownlinkConfigCommonSIB	SIB1	When present, it indicates the initial DL BWP the UE will use during RACH procedure
initialUplinkBWP-RedCap in UplinkConfigCommonSIB	SIB1	When present, it indicates the initial UL BWP the UE will use during RACH procedure
redCapAccessAllowed-r17	SIB4	Indicates if RedCap UE may access the frequency; prevents RedCap UEs from measuring neighbor cells not supporting RedCap
Logical Channel Identifier (LCID)	Msg3 / MsgA	Specific values for RedCap devices; used to identify the device as "RedCap" during Msg3
relaxedMeasurement-r17	SIB4	Adds "stationary" and "cell edge while stationary" concepts; when present, the RedCap device can apply some relaxations described in 3GPP 38.133
intra-SlotFH-r17	SIB1	A RedCap UE will apply different intra-slot PUCCH frequency hopping when this parameter is enabled

The first IEs listed in Table 5 pertain to the permission for a RedCap UE to camp in a cell or do so using half-duplex mode. The next IEs pertain to BWP, which allows flexible spectrum use to achieve power savings by dynamically adapting the assigned bandwidth depending on what the UE is doing. However, BWP offers limited value for RedCap devices because of the reduced maximum bandwidth (20 MHz).

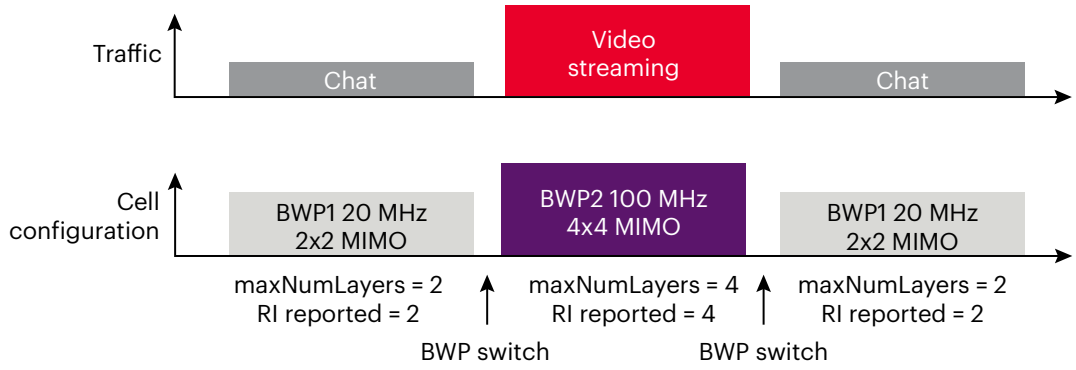


Figure 3. Example of use of different BWP in 5G NR devices

Bandwidth and power requirements

As discussed, RedCap UEs have a lower maximum bandwidth than other NR devices. This reduced bandwidth has implications for the RACH procedure. The network can allow the UE to use a specific initial BWP for RedCap devices or reduce the BWP size requirement to enable the RedCap UE to complete the attach process. The use of RedCap BWP during initial access (Msg1) indicates that the device is a RedCap device. The identification can also occur later in Msg3 if the device uses a RedCap logical channel identifier.

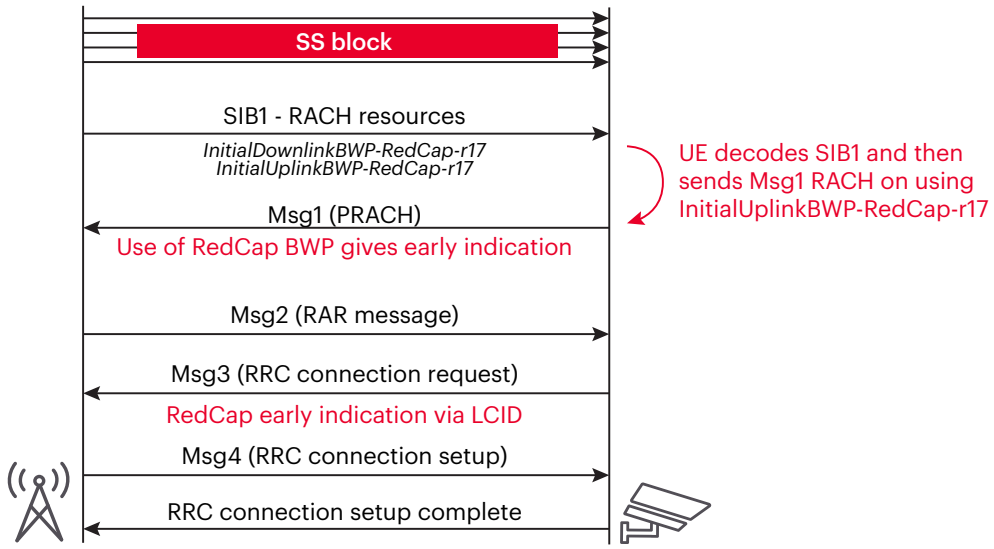


Figure 4. Indication of RedCap UE during RACH procedure

Another power-saving enhancement Release 17 implements for RedCap is the use of system frame number (SFN). This technique, which was available in LTE, allows an extension of disconnected receiver time (eDRX) to a maximum of 10.24 seconds, reducing power consumption in devices with long idle periods during operation.

To avoid handover errors, the use of maximum eDRX time may be restricted to stationary scenarios or situations when the device is not at the cell edge.

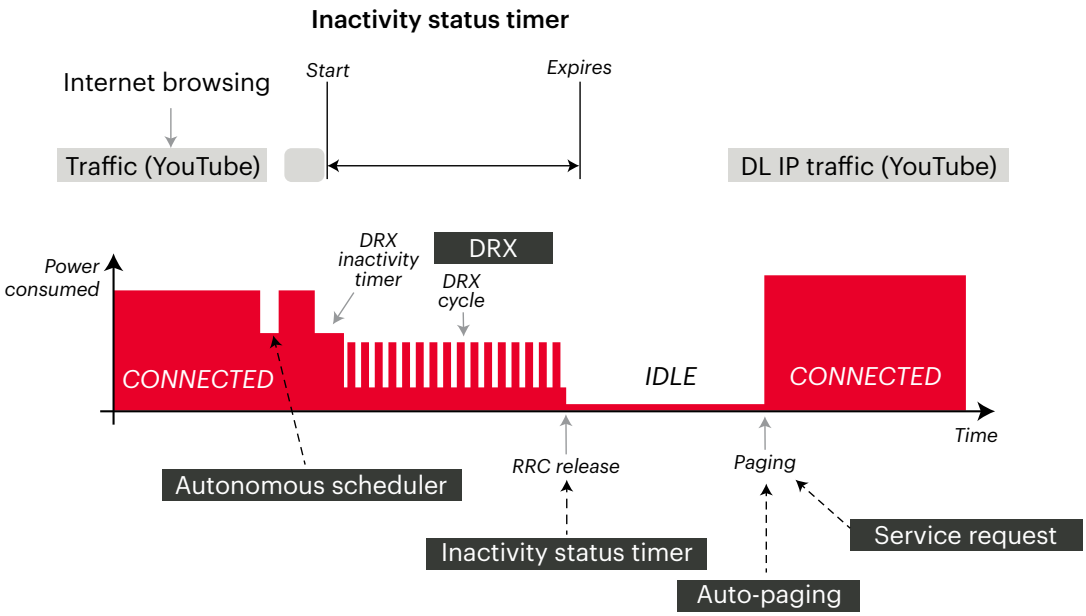


Figure 5. Example of a device using DRX before moving to idle and later reconnecting

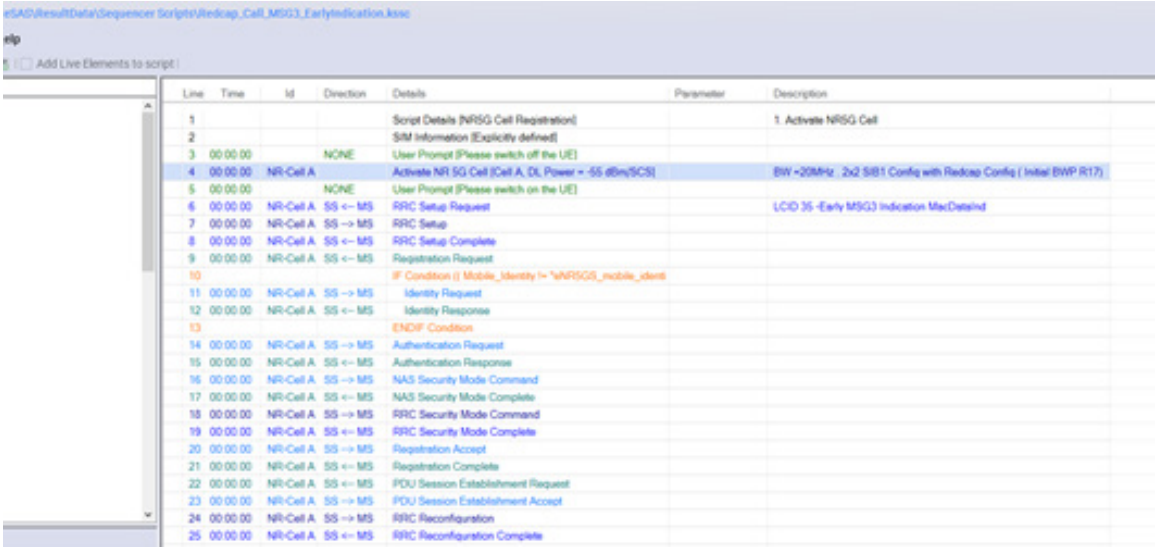
RedCap Signaling Test with UXM 5G

Keysight was the first to market with support for testing 100 MHz-wide cells for pre-5G, known as 5GTF. Since then, Keysight has supported the wireless industry in achieving other 5G NR milestones in Releases 15 and 16, from initial calls in different deployment modes and frequency ranges to achieving maximum data rates with record carrier aggregation configurations and total used bandwidth.

Figure 6. The Keysight UXM 5G is the leading wireless test platform for 5G. It supports additional radio access technologies, including LTE, C-V2X, 3G, and wireless local area networking.

Keysight offers support for Release 17 enhancements to 5G NR, including RedCap, with Keysight network emulation solutions. The comprehensive portfolio of solutions covers non-signaling and signaling testing in different domains, including protocol, radio frequency, functional verification, and performance testing in real conditions.

As discussed previously, Release 17 implements some changes to signaling parameters and procedures to ensure network support of RedCap devices. Device makers will need to ensure compatibility before they roll out commercial products. The Keysight S8701A Protocol R&D Toolset supports Release 17 ASN.1 and updated L1 to L3 procedures, which include specific testing of RedCap parameters to ensure that connectivity can be achieved and maintained.



Line	Time	Id	Direction	Details	Parameter	Description
1				Script Details [NRSG Cell Registration]		1. Activate NRSG Cell
2				SIM Information [Explicitly defined]		
3	00:00:00		NONE	User Prompt [Please switch off the UE]		
4	00:00:00	NR-Cell A		Activate NR 5G Cell [Cell A, DL Power = -55 dBm/SCS]		BW =20MHz 2x2 SIB1 Config with Redcap Config (Initial BWP R17)
5	00:00:00		NONE	User Prompt [Please switch on the UE]		
6	00:00:00	NR-Cell A	SS <-- MS	RRC Setup Request		LCID 35 -Early MSG3 Indication MacDataInd
7	00:00:00	NR-Cell A	SS --> MS	RRC Setup		
8	00:00:00	NR-Cell A	SS <-- MS	RRC Setup Complete		
9	00:00:00	NR-Cell A	SS <-- MS	Registration Request		
10				IF Condition ((Mobile_Identity != '%NRSGS_mobile_identi		
11	00:00:00	NR-Cell A	SS --> MS	Identity Request		
12	00:00:00	NR-Cell A	SS <-- MS	Identity Response		
13				ENDIF Condition		
14	00:00:00	NR-Cell A	SS --> MS	Authentication Request		
15	00:00:00	NR-Cell A	SS <-- MS	Authentication Response		
16	00:00:00	NR-Cell A	SS --> MS	NAS Security Mode Command		
17	00:00:00	NR-Cell A	SS <-- MS	NAS Security Mode Complete		
18	00:00:00	NR-Cell A	SS --> MS	RRC Security Mode Command		
19	00:00:00	NR-Cell A	SS <-- MS	RRC Security Mode Complete		
20	00:00:00	NR-Cell A	SS --> MS	Registration Accept		
21	00:00:00	NR-Cell A	SS <-- MS	Registration Complete		
22	00:00:00	NR-Cell A	SS <-- MS	PDU Session Establishment Request		
23	00:00:00	NR-Cell A	SS --> MS	PDU Session Establishment Accept		
24	00:00:00	NR-Cell A	SS --> MS	RRC Reconfiguration		
25	00:00:00	NR-Cell A	SS <-- MS	RRC Reconfiguration Complete		

Figure 6. A Keysight S8701A Protocol R&D Toolset test script for correct Msg3 RedCap UE early indication

In addition to supporting the latest R17 signaling procedures, the Protocol R&D Toolset offers reporting tools to analyze test results and help debug 5G NR devices, including those that support RedCap.

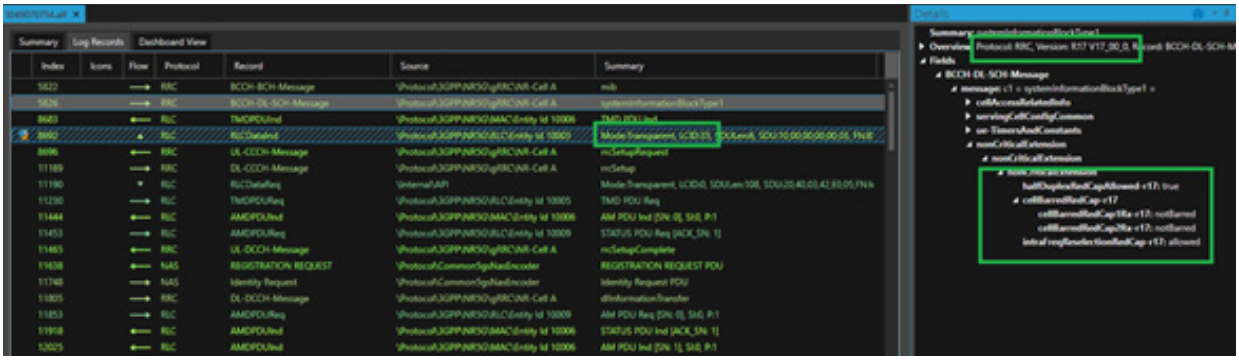


Figure 7. Log obtained with S8701A Protocol R&D Toolset during a RedCap test. Boxes show RedCap parameters.

For More Information

Find more insights on how to accelerate 5G innovation across the device workflow at the following links:

- Keysight 5G Network Emulation Solutions
- S8701A Protocol R&D Toolset
- S8702A RF Automation Toolset
- S8703A Functional KPI Toolset
- S8705A RF/RRM DVT & Conformance Toolset
- S8711A UXM 5G test application
- S8714A UXM 5G RF application

RedCap Will Boost IoT

3GPP has supported IoT devices since Release 13 using LTE or LTE-based technologies and has added enhancements in the later releases. Release 17 introduces support for IoT devices with 5G NR through a proposal that satisfies cost and power consumption requirements and adds more capacity than its LTE-based peers. This proposal makes RedCap a good choice for devices with capacity needs than cannot be satisfied with any of the previous IoT-specific technologies like NB-IoT and LTE Cat-M.

With RedCap, the network adapts to support devices needed for Industrial IoT, wearables, and security and surveillance applications.

The ability to support diverse device types on a single network brings additional benefits to network operators and service providers that can contribute to the success of new IoT-based businesses. While initial device launches may include support for LTE-based and 5G NR RedCap technologies, the rapid growth of 5G deployments and subscribers worldwide should hasten the transition to devices that use RedCap exclusively.

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