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Development of 5G NR RedCap devices

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Abstract. The subject of this paper is the RedCap technology. RedCap devices (known as Reduced Capability devices) are a new technology that is being studied by 3GPP in the R17 phase of 5G. RedCap can be defined as a lightweight version of 5G technology. The IoT application scenarios are extremely complex and diverse, and different scenarios have different requirements for network metrics. RedCap devices have emerged to fill the gap left by the withdrawal of 4G, i.e., to cover the needs of medium and high speeds. Specifically, it was designed to cover the needs of LTE Cat.1 and LTE Cat.4. Therefore, this article will introduce the reader to Release 17 RedCap devices by describing them from multiple perspectives, i.e. the history of RedCap devices, application scenarios, requirements, and their technical features. RedCap devices are well-balanced in their capabilities, using simpler demodulation (meaning significantly lower RF and baseband requirements), targeting bands with smaller spectrum bandwidths, and reducing the number of transceiver antennas and the number of MIMO layers. These changes have resulted in a reduction in the rate of RedCap devices, a reduction in coverage capability, and an increase in latency. Based on these changes, RedCap devices are expected to be 2-5 times less expensive than 5G. The main applications for RedCap are wearable devices (e.g. smart watches), industrial sensors and video surveillance devices.

Keywords: 5G, RedCap, NR

1. Introduction

With 3GPP freezing version 17, people are now in the phase of version 18. This also marks the beginning of the advanced version of 5G. 5G has three main application scenarios, namely enhanced mobile broadband, or eMBB, ultra-reliable and low-latency communications, or uRLLC, and large-scale IoT communications.

eMBB is an upgraded version of 4G. It mainly refers to smartphone devices and corresponding applications such as web, apps, email and video, which rely on Internet access. 5G upgrades to eMBB focus on network speed, bandwidth capacity and spectral efficiency. 5G new radios support different frequency ranges from Release 15 onwards, as well as multi-antenna systems, thus increasing the capacity of eMBB. For uRLLC [1] and large-scale IoT, the former is more concerned with reliability and latency, while the latter is concerned with the number of connections and energy consumption. Some of the most prominent applications are related to automation because of its low latency. For example, autonomous driving.

The application scenarios of IoT are extremely complex. Different scenarios do not require the same network metrics. Taking rate as an example, VR/AR, HD relay needs high speed connection, but remote meter reading (water meter, electricity meter), and synchronized data of shared bicycle, only low speed is needed. Compared with the rate, many application scenarios are more concerned about power consumption and cost. Relying on 5G alone, it is not possible to meet all the needs. So, at this stage, it is actually 5G and 4G technologies that are supporting these diverse scenarios. 2G and 3G were supporting some application scenarios that only needed low speed, and when they withdrew, IoT services migrated to LTE Cat.1, LTE Cat.4 and NB-IoT, that is, 4G and 5G. The question is, when 4G withdrew, how should these needs be met? RedCap devices are emerging to compensate for the 4G exit. In other words, NB-IoT and eMTC can be seen as a lighter version of 4G, while RedCap is a lighter version of 5G [2].

2. RedCap in R17

RedCap technology is officially proposed in 2019. Ericsson proposed the concept of lightweight 5G at the 3GPP RAN#86 meeting, tentatively named "NR Light", and proposed a project in this area. The proposal was adopted after discussion at the meeting. At 3GPP RAN#88, Ericsson explicitly launched a research project for low-complexity 5G terminals and approved it, renaming the lightweight 5G terminal as "RedCap" and officially launching the research. At 3GPP RAN#90e, Ericsson and Nokia proposed and approved a standardization project for RedCap, and officially launched RedCap standardization in 3GPP Release-17.

The end of Release 17 version 5G was officially announced by 3GPP at the RAN#96 meeting on 9 June 2022. In the previous release, 3GPP's Study Item project identified capability requirements for reducing the maximum bandwidth of the UE, the number of receiving antennas, the number of MIMO layers and the maximum modulation order. At the same time several companies eventually refined the performance of the RedCap device in various areas. These include bandwidth, number of MIMO layers to reduce the terminal complexity of RedCap devices, support for some identification technologies, DRX enhancements and more.

The Work Item project focused on several key technologies: firstly, the complexity of NR RedCap UE is reduced to a maximum bandwidth of 20MHz on the FR1 band. The maximum bandwidth has been reduced to 20 MHz in the FR1 band, and for the R15 and R16 versions of the eMBB UE system, a 2Rx system is supported for the FDD band, while the TDD band is 4Rx. This protocol defines a type of UE system and supports functions such as identification of UEs and access restrictions. The freeze on Release 17 has brought RedCap technology into the end product development phase, making it more focused. The sacrifice of communication capability in RedCap devices has resulted in a significant reduction in the cost of the chip, module and terminal design. This helps to expand the scale of the industry chain and drive the widespread adoption of 5G, enabling a more prosperous 5G ecosystem.

3. Typical application scenarios and the demand

3.1. Typical application scenarios

For the diverse 5G target scenarios, 3GPP has identified the following three types of capability requirements for typical RedCap applications: industrial wireless sensors, video surveillance, and wearable devices.

For wearable devices, mainly smart watches, smart bracelets, medical monitoring devices, etc., small size and low power consumption are generally required. These use cases which require low complexity and low cost implementation of terminals, and small size of terminals to meet the stringent space requirements of smart watches and other terminals, so that space can be provided for batteries to increase device endurance. The reference rate for wearable devices is around 5 to 50 Mbit/s, with peak rates of up to 150 Mbit/s and an ideal battery operating life of several days or even a week.

Industrial wireless sensors include pressure sensors, humidity sensors and motion sensors in industrial environments. The URLLC for these sensors has very high performance requirements, but also includes some relatively low-end applications with slightly lower communication performance requirements, smaller terminal size and low power consumption, which require 99.99% reliability and less than 100 ms latency when operating[3-5].

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For video surveillance equipment, 5G is used in scenarios such as urban management, industrial/agricultural or monitoring of various areas where there is a demand for real-time video surveillance to address security risk issues, enhance management tools, etc. The merging of 5G terminal modules with surveillance cameras provides a flexible, low-cost means of backhauling video surveillance. The large-scale application of video surveillance also requires low-cost 5G modules, with rates of 2-4 Mbit/s for economic video surveillance and 7.5-25 Mbit/s for ultra-high-definition video surveillance, with time delays of less than 500 ms[6, 7]. In many countries, such surveillance equipment is already widely used in civil security operations, vehicle monitoring and public security policing[8].

3.2. Demands

The overall demand for RedCap focuses on the size and cost of its devices.

The large size and high price of current 5G modules affects the application of typical services and makes it difficult to match the industry's demand for scale.

In terms of size, the large size of current 5G modules makes integration difficult, especially for very small devices, and industry has raised the need for a certain degree of tailoring of terminals. In terms of price, current 5G eMBB modules are still very expensive, with cameras used in industries such as security and car monitoring costing up to several hundred dollars, and wearable products such as smartwatches costing more on average because of their greater size requirements, with high costs limiting the scale of these industry applications to some extent.

Therefore, in order to match the size and price requirements of 5G chips and modules, terminal complexity needs to be reduced to lower costs. Based on RedCap's research objectives, the cost of its terminals after tailoring will be substantially lower than that of eMBB terminals.

For wearable devices, the main requirement is in the power consumption, or range, of the device. Low power consumption is the technical key for wearable devices, and improved power saving capability can accelerate their upgrade for 5G use. The current demand for LTE Cat.1 and Cat.4 is high in mainstream electronic watches, and their endurance is relatively short. For the use of wearable devices in 5G scenarios, reducing power consumption is the focus of standardisation, and in this industry, the current expectation is for a maximum endurance of 1 to 2 weeks.

For industrial sensors, the main requirements are in terms of latency as well as their reliability. Industrial wireless sensors or some control scenarios have certain requirements for latency, and the requirements are for RedCap devices to inherit the existing 5G URLLC capabilities based on its RTT (round-trip time) to increase by 5-10 ms compared to URLLC, with latency requirements of less than 100 ms. For security services, the requirements are even higher, with latency requirements of 5-10 ms. 5 to 10 ms.

For video surveillance equipment, the key requirement is in the speed. The camera uploads the captured images and video data streams to the platform in real time, therefore, it has relatively high requirements for speed stability.

Video surveillance is growing rapidly in the industry, with the proportion of end-side AI intelligent processing functions increasing year on year, and the industry expects to increase the use of 5G to improve wireless rates. With the trend of ultra-HD cameras and AI recognition and processing in video surveillance becoming a necessity, the need to ensure adequate rate experience in the transmission process has become a key concern for the industry, as different products have different levels of compression.

4. Characteristic of RedCap

3GPP had carried out research into RedCap devices to achieve their terminal characteristics. These include both complexity reduction and energy efficiency.

4.1. complexity reduction

One aspect of reducing complexity is to reduce the number of UE receiving antennas and the number of MIMO (multiple-input multiple-output) layers By reducing the number of layers, the complexity and cost of the device UE is reduced. Based on the cost evaluation model provided by 3GPP, the cost of the UE is reduced by approximately 40% when the number of receiving antennas is reduced to 2 for the RedCap UE and by approximately 60% when the number of receiving antennas is reduced to 1 for the NR UE's 2Tx4Rx system. The main cost reduction modules include the UE RF transceiver including antenna arrays, power amplifiers, filters, transceivers, duplexers/switches and part of the baseband processing module. In general, the cost ratio between the baseband and RF modules is approximately 6:4.

The second aspect of complexity reduction is the reduction of the bandwidth capacity of the UE. Reducing the UE bandwidth reduces the requirement for UE baseband processing power. Based on the cost assessment model provided by 3GPP, the UE cost can be reduced by more than 30% by reducing the maximum UE bandwidth from 100 MHz to 20 MHz in the FR1 band. The main modules that reduce the cost of the terminal are some of the baseband modules, such as the analogue-to-digital/digital-to-analogue converter, the FFT (fast Fourier transform) module, the IFFT (inverse fast Fourier transform) module, the receive processing block, the LDPC (low density parity check) decoding module, etc.

The third aspect of complexity reduction is the use of half duplex-frequency division duplexing (FDD). Compared to full duplex-frequency division duplexing in NR equipment, which is more costly with duplexers, half duplex-frequency division duplexing is introduced in RedCap, i.e. transmitting and receiving on separate frequencies at different moments in time. Components such as switches and low-pass filters are used instead of duplexers, and the complexity and cost of the UE is reduced.

A final aspect of this reduction in complexity is the use of simpler demodulation methods. By reducing the maximum number of modulation steps, the complexity and cost of the UE is reduced. In NR, the UE supports up to 256QAM modulation and for the RedCap UE the 3GPP discussions set it to 64QAM mandatory and 256QAM optional. Based on the cost assessment model provided by 3GPP, the change from 256QAM to 64QAM modulation in the FR1 band reduces the cost of the UE by approximately 6%, with the reduction in complexity achieved mainly in the RF transceiver and some of the baseband modules [9].

4.2. Energy efficiency improvement

Reducing power consumption is an ongoing issue since the 5G era. 5G terminals have a strong demand for energy saving and appropriate technologies can significantly improve the battery life of the devices.

The UE performs PDCCH detection and caching in each time slot, however, in most time slots there is little or no data, and PDCCH monitoring in standby takes up more than half of the communication power. Unnecessary PDCCH monitoring increases the energy consumption of the UE, therefore, UE power saving can be achieved by reducing PDCCH monitoring [10].

On the other hand, increasing the DRX period of RRC inactive UEs consumes UE power for inactive RedCap UEs with frequent wake-ups, and based on the extended DRX mechanism introduced in 3GPP's Release-13, the UE power saving is continued in Rel-17 by increasing the DRX period for RedCap UEs. The 3GPP evaluation results show that increasing the DRX period above 10.24s results in a significant energy saving gain for eDRX (extended discontinuous reception) in the RRC idle or inactive state, which is beneficial for battery life, and is particularly suitable for terminals with large service cycles.

5. Conclusion

In summary, with the introduction of RedCap, terminal complexity has been significantly reduced compared to traditional 5G eMBB terminals, and it can take full advantage of the large bandwidth of NR, inheriting various excellent features of NR, such as UPF sinking and better power consumption, making it very attractive to the industry. With the 3GPP Release 17 phase RedCap standardisation work, RedCap technology will be able to make a significant impact in its application areas with the full support of the industry. In addition, RedCap will continue to evolve to meet the demand for lower cost and better power consumption, and will focus on bandwidth reduction and power saving in 3GPP Release 18 to further optimise the low-cost 5G terminal technology and its integration with the network.

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There are some limitations in this article. Firstly, the RedCap device is one of the most advanced 5G technologies on the market and there are many technical details and principles that the author does not have access to. Therefore, when describing its functionality, the description may not be the latest version (Release 18). This article focuses on the technical details of Release 17. Secondly, most of the technical details in this article are based on a single company's RedCap technology, which is developed by different companies on the market.

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