Advancing 5G Connectivity for Massive IoT with HD-FDD eRedCap

A standardised approach to enabling scalable, cost-efficient, and power-optimised connectivity through Half-Duplex Frequency Division Duplex eRedCap.

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Executive Summary

Overview

As the evolution of 5G New Radio (NR) continues, the demand for versatile connectivity solutions grows across industrial, enterprise, and IoT sectors. While traditional 5G implementations deliver high data rates and low-latency performance, many emerging applications require a different balance: broader coverage, lower device complexity, reduced power consumption, and cost-effective deployment at scale. Existing LPWA technologies, including NB-IoT and LTE-M, have successfully addressed low data-rate use cases on 4G networks and will continue to play a role within the 5G ecosystem. However, a gap remains for a mid-to-low data-rate solution that delivers 5G NR benefits at a significantly lower cost than established 5G NR technologies.

Enhanced Reduced Capability (eRedCap), particularly with Half-Duplex Frequency Division Duplex (HD-FDD) operation in 3GPP Release 18, is positioned to fill this gap. HD-FDD eRedCap allows devices to transmit and receive on the same carrier at different times, which significantly lowers RF complexity and power consumption while improving heat dissipation, device sensitivity, size, and overall cost. These are key attributes for massive IoT and low power wide-area networks.

However, realizing the full potential of HD-FDD eRedCap as a 5G NR low-cost alternative solution requires cohesive industry support:

- **Chipset Vendors:** Must integrate HD-FDD eRedCap capability to enable low-cost, power-efficient device designs suitable for battery-operated and embedded IoT devices.
- **Network Equipment Vendors:** Need to implement network-side support for HD-FDD eRedCap operations, ensuring optimized scheduling, resource allocation, and coverage extension features.
- **Mobile Network Operators:** Need to champion and deploy HD-FDD eRedCap-capable networks and enable 5G eRedCap Roaming to ensure global support of a 5G NR mid-low tier option.

Enabling HD-FDD eRedCap throughout the ecosystem will expand 5G's ability to serve a broader spectrum of IoT and machine-type communication use cases. This white paper details the technical rationale, use cases, and business imperatives for immediate industry action to mainstream HD-FDD eRedCap, establishing it as the definitive long-term option for mid-tier devices in the 5G ecosystem.

For further education on RedCap and eRedCap, please see this GSMA paper on the topic:

5G RedCap and eRedCap: The Future of Efficient IoT Connectivity

Abbreviations

TERMS	DESCRIPTION
3GPP	3rd Generation Partnership Project
DRX	Discontinuous Reception
DL	Downlink
eDRX	Extended Discontinuous Reception
eNB	Evolved Node B
FD	Full Duplex
FDD	Frequency Division Duplexing
FR1	Frequency Range 1
GSMA	GSM Association
HD	Half Duplex
IoT	Internet of Things
IP	Internet Protocol
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-M	Long-Term Evolution Machine Type Communications
M2M	Machine-to-Machine
NB-IoT	Narrowband IoT
NTN	Non-Terrestrial Network
RAN	Radio Access Network
UE	User Equipment (User Device)
UL	Uplink

References

TERMS	DOC NUMBER	DOC NUMBER
[1]	3GPP TS 38.331	NR; Radio Resource Control (RRC); Protocol specification
[2]	3GPP TS 38.101-1	NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone
[3]	GSMA Whitepaper	RedCap/eRedCap for IoT
[4]	NG.114	IMS Profile for Voice, Video and Messaging over 5GS;.2.1
[5]	3GPP TR 38.875	Study on support of reduced capability NR devices
[6]	3GPP TR 38.865	Study on further NR RedCap UE complexity reduction
[7]	3GPP TS 38.306	NR; User Equipment (UE) radio access capabilities

1. HD-FDD eRedCap technology considerations

1.1 Background

In recent years, 3GPP has introduced standard support for new 5G UE types with low complexity and low power consumption, suitable for IoT use cases. It began in Release 17 with the introduction of reduced capability (RedCap) UEs [1], which have relaxed data rate requirements compared to regular 5G UEs. Another step was taken in Release 18 with the introduction of enhanced RedCap (eRedCap) UEs [1] targeting an even lower segment of IoT use cases.

The most important simplifications implemented by RedCap and eRedCap UEs compared to regular 5G UEs concern peak data rates, transmit/receive bandwidths, number of antennas, and duplex operation. There are also a few other simplifications, but these are the main ones. In the following, we focus on UEs for FDD bands, which corresponds to frequency bands below ~2.6 GHz [2].

- **Reduced peak data rates:** Regular 5G UEs typically have peak rates of hundreds of Mbps or more, whereas RedCap UEs have peak rates of approximately 85-226 Mbps in downlink and 90-120 Mbps in uplink depending on implementation choices and network configuration, and eRedCap UEs are limited to a peak rate of 10 Mbps in downlink and 10 Mbps in uplink.
- **Reduced transmit/receive bandwidths:** Regular 5G UEs typically have an RF bandwidth of 100 MHz or more (and can aggregate bandwidth across multiple carrier frequencies), whereas RedCap and eRedCap UEs have an RF bandwidth of 20 MHz (with no possibility for carrier aggregation). In addition, eRedCap UEs can optionally implement a further restriction of the bandwidth used for the actual data transmission, corresponding to a baseband bandwidth of 5 MHz.
- **Reduced number of receive antennas:** Regular 5G UEs are typically required to implement two receive antennas for frequency bands below 2.5 GHz, and four receive antennas for frequency bands above 2.5 GHz (and a corresponding number of MIMO layers). RedCap and eRedCap UEs are allowed to implement just a single receive antenna (without MIMO) and can optionally implement two receive antennas (with two MIMO layers).
- **Half-duplex operation:** For paired (FDD) bands, regular 5G UEs implement full-duplex FDD (FD-FDD) operation, whereas RedCap and eRedCap UEs are allowed to implement half-duplex FDD (HD-FDD) operation, meaning that they don't need to support simultaneous transmission and reception. RedCap and eRedCap UEs can optionally implement support for FD-FDD operation. This simplification is not relevant for unpaired (TDD) bands, since TDD operation already uses half duplex.

The reduced RF bandwidth (20 MHz) is mandatory for all RedCap and eRedCap UEs, and the 10-Mbps peak rate limitation is mandatory for all eRedCap UEs. Whether to implement the other simplifications is up to the UE implementation. The more simplifications that are implemented, the more substantial the complexity reduction will be compared to regular 5G UEs. GSMA published a white paper on "RedCap/eRedCap for IoT" in February 2025 [3]. In the present paper, we provide additional analysis specifically for HD-FDD eRedCap UEs, which are the simplest standardized 5G UEs.

1.2 Technical aspects

3GPP Release 18 enables eRedCap implementation using both FD-FDD and HD-FDD duplexing methods. FD-FDD transmits and receives simultaneously on separate channels, requiring special duplex filters to manage channel separation. These filters prevent interference during transmission but add much complexity and cost to the device as is described later.

In contrast, HD-FDD operates on the same separate frequencies but transmits and receives at different time intervals. This approach eliminates the need for duplex filters, significantly reducing cost and complexity. HD-FDD has become the standard operation mode for all LTE-M and NB-IoT deployments worldwide and is widely considered a key element for their successful deployment. An illustration of FD-FDD and HD-FDD operation modes is depicted opposite.

[1] 3GPP TS 38.331 - NR; Radio Resource Control (RRC); Protocol specification
[2] 3GPP TS 38.101-1 - NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone
[3] GSMA Whitepaper - RedCap/eRedCap for IoT

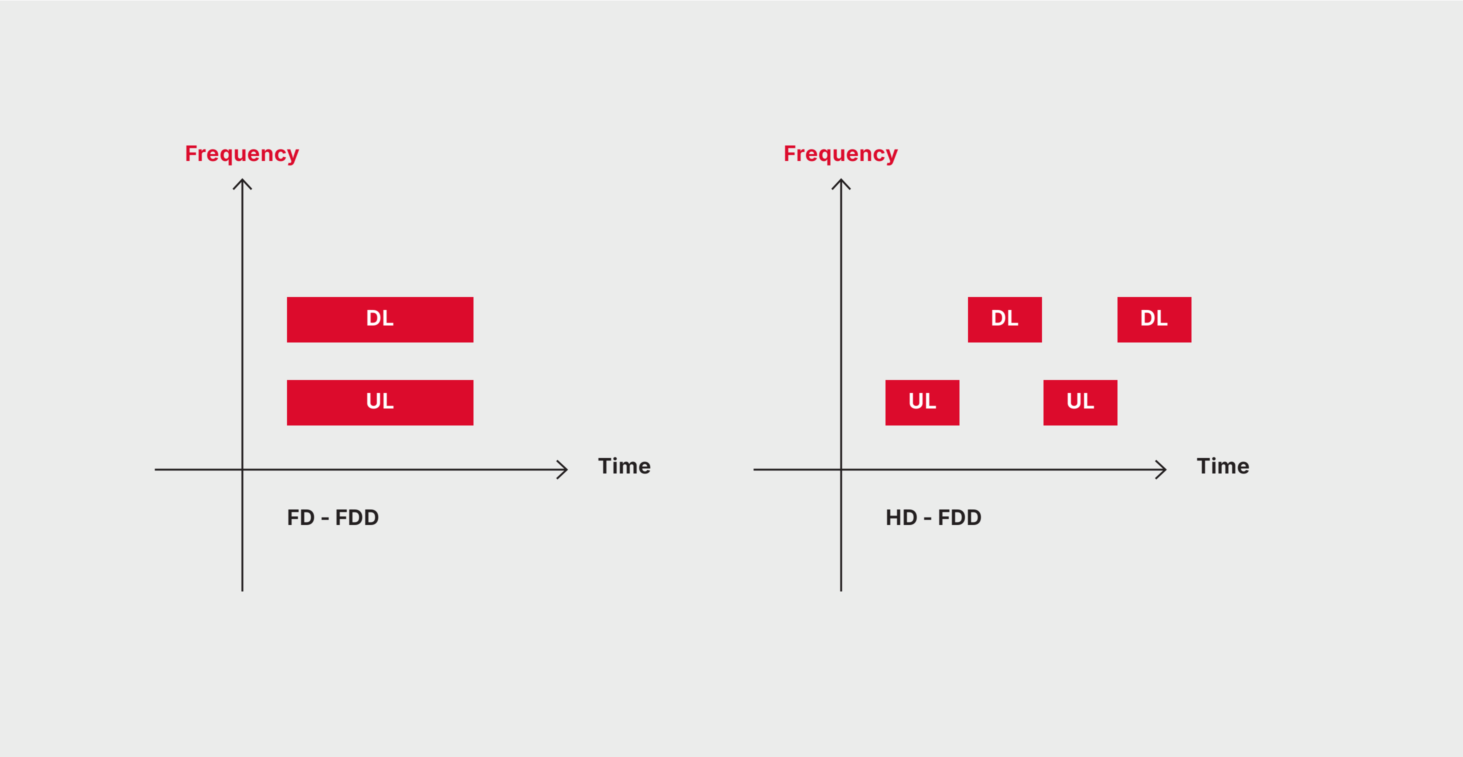

Figure 1, Description of FD-FDD and HD-FDD operation modes

As duplexers are frequency (hence band) specific, different elements need to be populated to support plurality of bands. On the other hand, HD-FDD design is agnostic to bands usage which dramatically simplifies the complexity and cost of resulting product, as is depicted in below image.

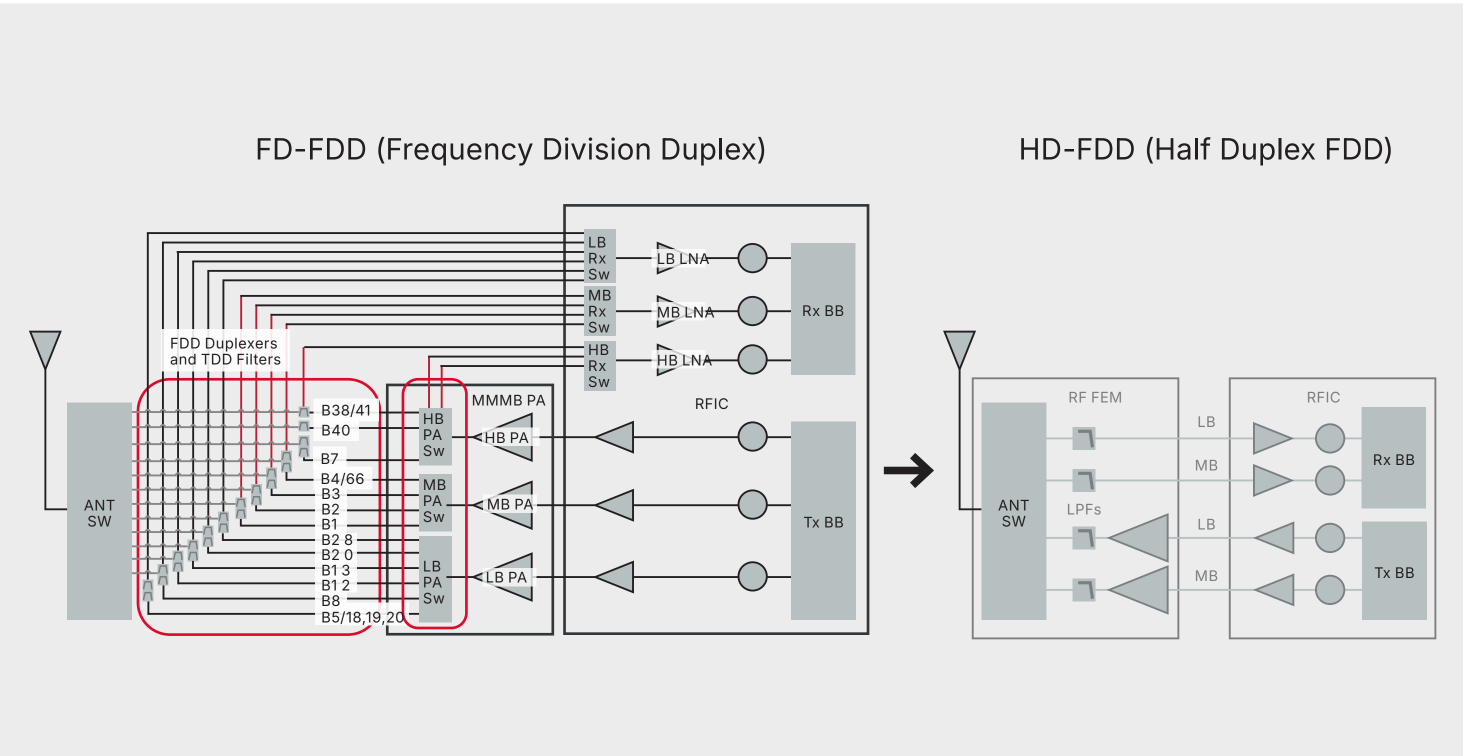

Figure 2, Illustration of eRedCap FD-FDD and HD-FDD worldwide (global SKU) designs

The fundamental difference between FD-FDD and HD-FDD eRedCap designs, illustrated above, significantly impacts product properties as is described herein:

- **Worldwide single design:** Since HD-FDD design typically does not have any band-specific components, it allows true single SKU module design, enabling significant economy of scale.
- **Size:** Adding multiple band-specific duplexers and PA switches in FDD design results with significant added module area.
- **Components:** The HD-FDD design enables manufacturers to eliminate the need for duplexers and PA switches, resulting in a simpler overall design.
- **Power consumption:** FD-FDD duplexers and PA (define) switches adds also 2-2.5dB to transmission path insertion loss. This means that PA should transmit data at ~2.5dB added power in order to meet required Tx power at antenna port. This significantly adds to FD-FDD eRedCap UE power consumption and required heat dissipation. Furthermore, since HD-FDD UE only transmits or receives data at each point in time, its peak current consumption is further reduced compared to FDD UE. Those two considerations bring HD-FDD eRedCap UE power consumption to be x2-x3 lower than FDD UE. Currently, HD-FDD eRedCap is only used with Power Class 3.
- **Receiver sensitivity:** The 2-2.5dB added insertion loss described above impacts also receiver path. That means that UE SINR is proportionally reduced, impacting cell coverage.
- **Capacity:** Both FD-FDD and HD-FDD eRedCap devices reach about the same capacity (contradicting a common mis-concept that FD-FDD performance is superior). This aspect is analyzed in next paragraph.

A common misconception is that HD-FDD suffers from dramatic reduced network capacity and device throughput compared to FD-FDD device. This arises from the fact that in HD-FDD only Tx or Rx are active at each point in time while FD-FDD device can activate both in parallel. This is a wrong assumption as is described herein:

- **Network capacity:** Operator's network capacity is kept the same as gNB scheduler sets separate UL and DL grants at same time to different UEs which are not co-located. This achieves similar network capacity as in FD-FDD case. Same approach is used today in LTE-M and NB-IoT deployments.
- **UE throughput for UL dominated traffic:** Most IoT devices are UL dominated (e.g. water / gas / electricity meters, alarm panels etc). 3GPP standard allows efficient scheduling of UL grants in a way that can reduce the performance difference between FD-FDD and HD-FDD UEs (see figure 3 below). Most slots can be used for UL data, but some slots need to be used for DL to periodically receive essential information (such as SSB, CSI-RS, and TRS) to maintain the connection. In addition, DL feedback signalling (e.g. TCP/RLC ACKs) and timing interactions for CSI transmissions should be considered. This results in ~25% peak throughput degradation for HD-FDD compared to FD-FDD which is considered a reasonable impact.
- Note that in practical deployment scenarios the cell is shared by several UEs where each UE gets different time/frequency allocations during each slot. That results in no practical throughput loss for HD-FDD UE compared to FD-FDD UE.
- **UE throughput for DL dominated traffic (e.g. FOTA):** This scenario is dominated by DL grants where from time to time an UL ack/nack grant must be provided. Some additional UL traffic is also expected (e.g. TCP/RLC ACKs, CSI reports, SRS transmissions etc). In that case HD-FDD differs from FD-FDD UE during the transmission of those UL slot (as FD-FDD UE can still use this slot for additional DL grant in parallel). That results in ~25% peak throughput degradation (1-2 slots every 9 slots) which is considered a reasonable impact. This scenario is illustrated in figure 4 below.
- Since an HD-FDD UE cannot transmit and receive at the same time, an HD-FDD UE with symmetric UL and DL traffic will suffer from ~50% throughput degradation compared to an FD-FDD UE; however, this is considered as a very uncommon usage scenario for IoT device.

To summarize: HD-FDD network capacity and UE practical throughput are kept similar as FD-FDD for most of eRedCap IoT usage scenarios (e.g. UL or DL dominated traffic)

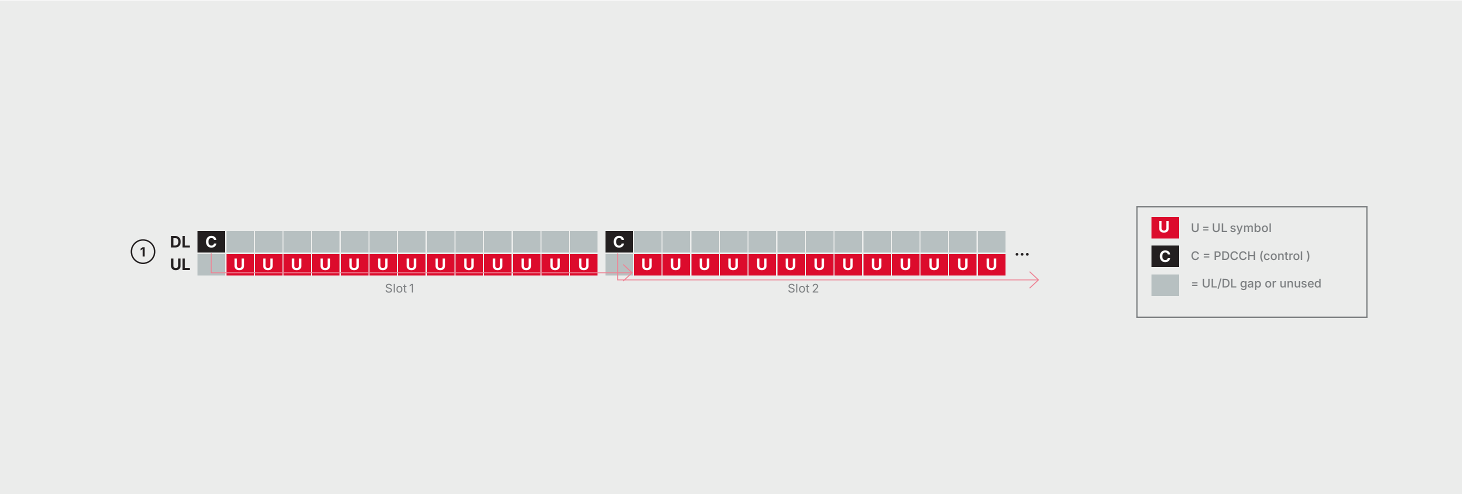

Figure 3, UL dominated traffic (IoT most common scenario)

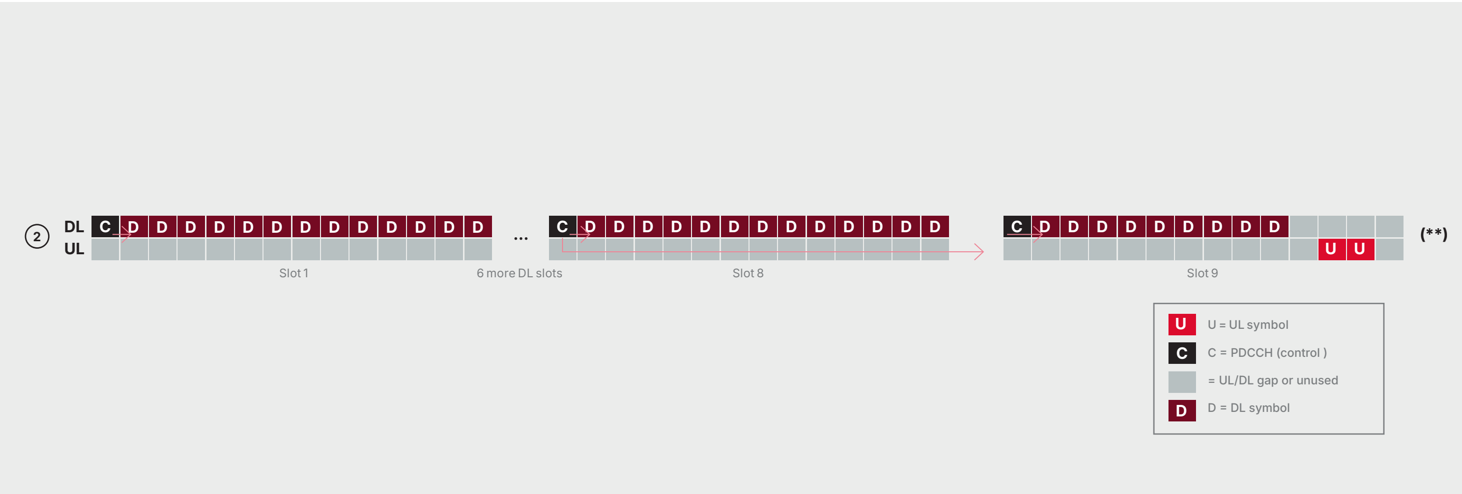

Figure 4, DL dominated traffic

An additional important comparison is Cat 1bis vs. HD-FDD throughput comparison as HD-FDD eRedCap is planned to be a cost-efficient replacement for Cat 1bis. Comparing Cat 1bis and HD-FDD eRedCap provides benefit for eRedCap enabled devices as their UL peak throughput is defined to be 10Mbps (vs. 5Mbps in Cat 1bis) while allowing better modulation schemes further improving UE efficiency. A general recommendation is for eRedCap devices to utilize a single antenna.

For conclusion: deploying HD-FDD devices as the key path for eRedCap deployment is a crucial aspect for the success of eRedCap IoT industry as it provides about the same network capacity and throughput while dramatically reducing module cost, area and power consumption, improving performance and cell reach and allowing a single design to serve global markets hence further reducing costs and engineering efforts.

HD-FDD eRedCap is suitable for all of these IoT use cases. The additional throughput provided by full duplex operation is not required for any of them.
IMS voice service (VoLTE) can be supported by the existing LTE Cat 1/ Cat 1bis and LTE-M technologies, although VoLTE for LTE-M is not widely deployed. It is expected that HD-FDD eRedCap devices and networks will be able to support IMS voice service (VoNR) in a similar manner [4]. Whether the device implements support for it is a design choice that depends on the targeted use cases. The achievable quality and coverage may depend on the actual network deployment.

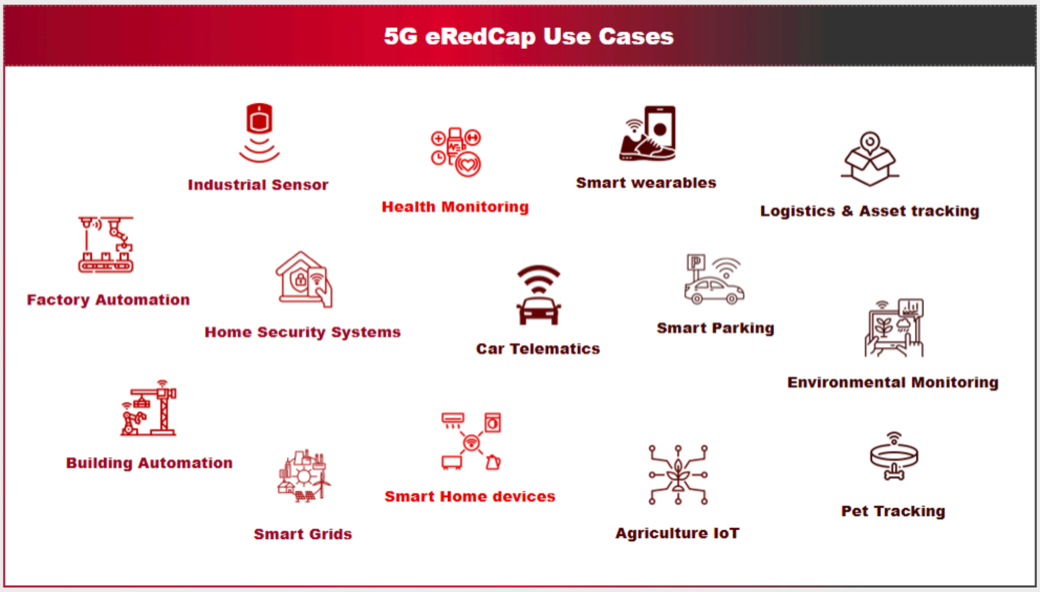

Figure 4, DL dominated traffic

[4] NG.114 - IMS Profile for Voice, Video and Messaging over 5GS;.2.1

1.3 Coverage aspects

3GPP has carried out coverage evaluations for RedCap and eRedCap, which are captured in 3GPP TR 38.875 [5] and 3GPP TR 38.865 [6], respectively. According to these studies, RedCap and eRedCap UEs will have similar service coverage as regular NR UEs deployed in the same frequency band, but with a reduced data rate, as expected. The reason that RedCap and eRedCap UEs have similar coverage as regular NR UEs despite the reduced number of receive antennas is that the NR coverage is typically uplink-limited, meaning that the reduced number of receive antennas (which only affects the downlink) does not have a large impact on the overall coverage.

RedCap/eRedCap UEs are also expected to have similar coverage as regular LTE UEs such as Cat 1/ Cat 1bis if they are deployed in the same frequency band with the same number of UE receive antennas. However, LTE-M (Cat-M1) UEs have mandatory support for coverage enhancement mode A (CE mode A), which means that they can have better coverage than regular LTE/NR UEs.

NR supports several coverage enhancement features [7] [1]. For example, Release 16 introduced dynamic PUSCH repetition. Releases 17 and 18 introduced several features such as enhancements to PUSCH/PUCCH repetition, support for DMRS bundling, transport block over multiple slots (TBoMS), and PUSCH power boosting capability. Release 19 introduced support for UE power class 2 (26 dBm) for RedCap/eRedCap. If RedCap/eRedCap UEs and networks implement support for one or more of these features, the coverage can be improved beyond regular LTE/NR coverage.

[1] 3GPP TS 38.331 - NR; Radio Resource Control (RRC); Protocol specification
[5] 3GPP TR 38.875 - Study on support of reduced capability NR devices
[6] 3GPP TR 38.865 - Study on further NR RedCap UE complexity reduction
[7] 3GPP TS 38.306 - NR; User Equipment (UE) radio access capabilities

1.4 Fallback considerations

When considering fallback mechanisms for HD-FDD eRedCap, one must take into consideration regional constraints and ecosystems.

LTE-M (HD-FDD) as fallback

Pros:

— The natural fallback mechanism for HD-FDD eRedCap is LTE-M as both solutions share HD-FDD topology. That would provide the simplest, single SKU and least-cost model for the technology.

Cons:

— That does present some challenges. Firstly LTE-M is not always supported across all regions yet. And LTE-M supports lower data rates than Cat-1 and Cat-1bis.

LTE Cat 1/ Cat 1bis (FD-FDD) as fallback

Pros:

— Global support would require fallback to a higher-capability technology such as LTE Cat 1bis. Cat 1bis is a good middle ground, balancing cost impact and capability. It can also be supported on any network that supports LTE Cat-1.

Cons:

— The challenge will be to limit the bands that are supported on a given device. This will likely lead to regional variants that ensure support in various locations. A global SKU would be harder to attain due to the large variety of band support required.
— Also, as mentioned earlier, Cat-1/1bis devices do not exhibit the same Coverage Enhancement capabilities as eRedCap or LTE-M devices and hence could raise some challenges in use case scenarios requiring excellent network coverage, e.g., deep-indoor coverage.

So, if a fallback option is needed, there are two available fallback options (LTE-M and Cat 1/1bis), each one with its own pros and cons that should be considered when deciding which option that is most suitable for a given use case.

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