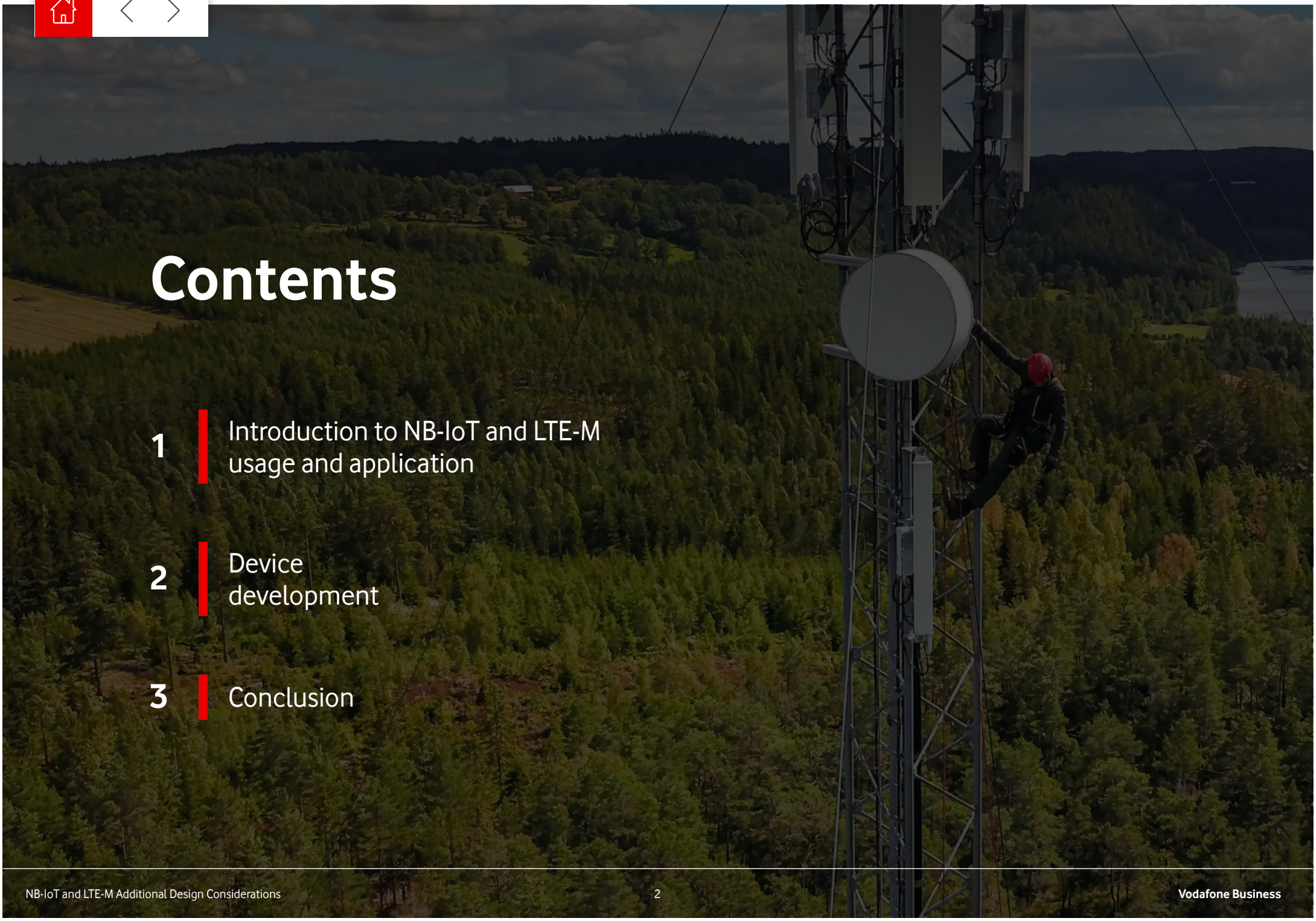

NB-IoT and LTE-M
Additional Design
Considerations
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1. Introduction to NB-IoT and LTE-M usage and application

1.1 Use case considerations and capability of LPWA

There has been a rapid evolution of technology over the last 30 years, from 1st generation to 5th generation technologies. In recent years, there had been an identifiable gap in the technology market for an evolved concept, which would provide connectivity (bearer service) for low power bandwidth-limited devices. These devices, for example water meters and connected sensors, would only need to transmit a small amount of data at infrequent intervals, allowing the hardware to have a form of longevity.

These requirements led to the 3GPP releasing specifications for the requirements and capabilities for Low Power Wide Area Networks, offering enhanced capability such as enhanced coverage penetration for connectivity in remote or underground locations and extended battery life, which is not part of the current specifications for legacy GSM, GPRS, UMTS and LTE.

Vodafone supports Narrowband-IoT (NB-IoT) and Long Term Evolution for Machine Type Communication (LTE-M) as LPWA technologies utilising licensed and secured spectrum.

The use cases of NB-IoT and LTE-M application mostly apply to devices that have infrequent and low data rate transmissions. It should be highlighted that NB-IoT does not support inter-handover or QoS, leading to an inability to provide VoLTE capability. However, voice capability is possible on LTE-M as VoLTE but currently this is not supported on Vodafone networks.

The battery for an NB-IoT device could theoretically last for around 10-15 years, while for LTE-M this is approximately 10 years; however, that is if a developer considers the LPWA network behaviour and utilises features developed for improved utilisation such as extended Discontinuous Reception (eDRX), Power Save Mode (PSM) and Release Assist. These new network features are available within most of the Vodafone markets with LPWA. There are also other major items to consider in the application design like the frequency in data transfer, throughput, expected latency and device adaptability for a variation of radio access networks, referred to as RAN awareness, when identifying the use case.

Developing a device that does not adhere to these simple technology considerations, will most likely affect the performance and battery lifespan of an LPWA-capable device and the outcome could be observations of a completely different behaviour in a live network environment from a simulated environment.

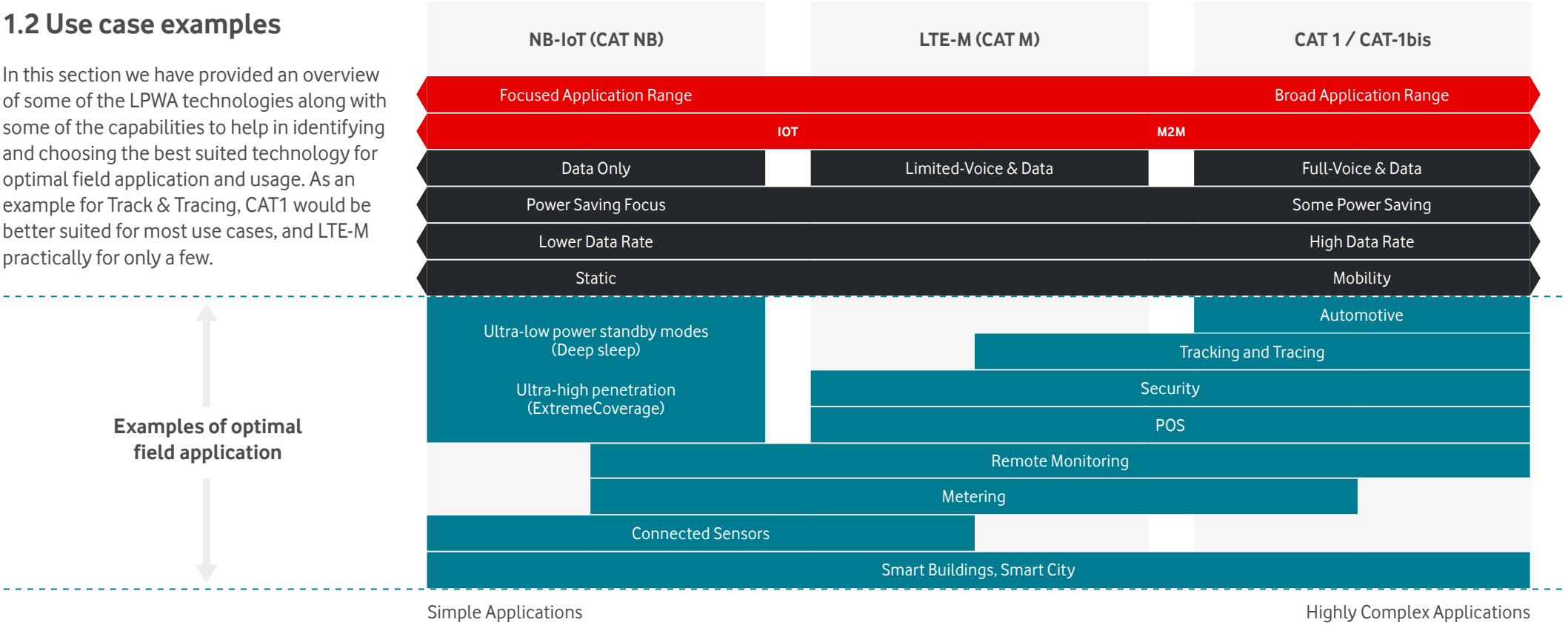
To avoid such situations, we do advise that customers and developers alike reach out to a local Vodafone sales representative prior to application and device development. Our sales representative will then be able to engage and open discussions with our technical expert teams; this could also include the usage of our Vodafone IoT Device Test and Support Services where we can organise via Professional Services where advised as an identifiable requirement.

With Vodafone's Low Power Wide Area Network's **(LPWA) Explorer Consultancy Service**, we offer professional consultancy and support – the Vodafone IoT expert consultant will help you explore the possibilities of LPWA for your business with a general overview of Narrowband-IoT and LTE-M.

1. Introduction to NB-IoT and LTE-M usage and application

1.2 Use case examples

In this section we have provided an overview of some of the LPWA technologies along with some of the capabilities to help in identifying and choosing the best suited technology for optimal field application and usage. As an example for Track & Tracing, CAT1 would be better suited for most use cases, and LTE-M practically for only a few.



Vodafone has completed several use cases for NB-IoT and LTE-M. Please visit our Vodafone Business IoT webpage for more information.

1. Introduction to NB-IoT and LTE-M usage and application

1.3 How does NB-IoT and LTE-M compare with other LPWA technologies?

In this table we can see how NB-IoT and LTE-M compares to other technologies that are also considered as LPWA technologies.

Generally, an NB-IoT only module is relatively cheaper in comparison to an LTE-M module. SigFox and LoRA are proprietary and come with their own device and software costs. The usage of unlicensed spectrum might have some benefits in terms of network costs; however, usage of unlicensed spectrum will surely increase the network signal's vulnerability to external interference whether deliberate or accidental. Vodafone is committed to providing a secure environment for MTC devices and will use its licensed spectrum and security-enabled SIMs to assure this. The other capability which identifies enhanced performance is the maximum coupling loss (MCL) available with NB-IoT, which provides deep coverage penetration.

			Licensed		
	Unlicensed 1 (SigFox)	**Unlicensed 2** (LoRaWAN)	**NB-IoT**	**LTE-M**	**EC-GSM-IoT**
Coverage (MCL)	160 dB	157 dB	**164 dB**	**155.7 dB**	164 dB
Technology	Proprietary	Proprietary	**Open LTE**	**Open LTE**	Open 2G
Spectrum	Unlicensed	Unlicensed	**Licensed (LTE/any)**	**Licensed (LTE)**	Licensed (GSM)
Downlink data rate	< 0.1 kbps	< 10 kbps	**450 bps - 150 kbps**	**300 bps - 800 kbps**	0.5 - 180 kbps
Uplink data rate	< 0.1 kbps	< 10 kbps	**300 bps - 220 kbps**	**300 bps - 600 kbps**	0.3 - 150 kbps
Battery life (200 b/day)	10+ years	10+ years	**15+ years**	**10+ years**	10+ years
Module cost	-	-	**< $6**	**< $10**	< $6
Security	Low	Low	**Very high**	**Very high**	Very high

1. Introduction to NB-IoT and LTE-M usage and application

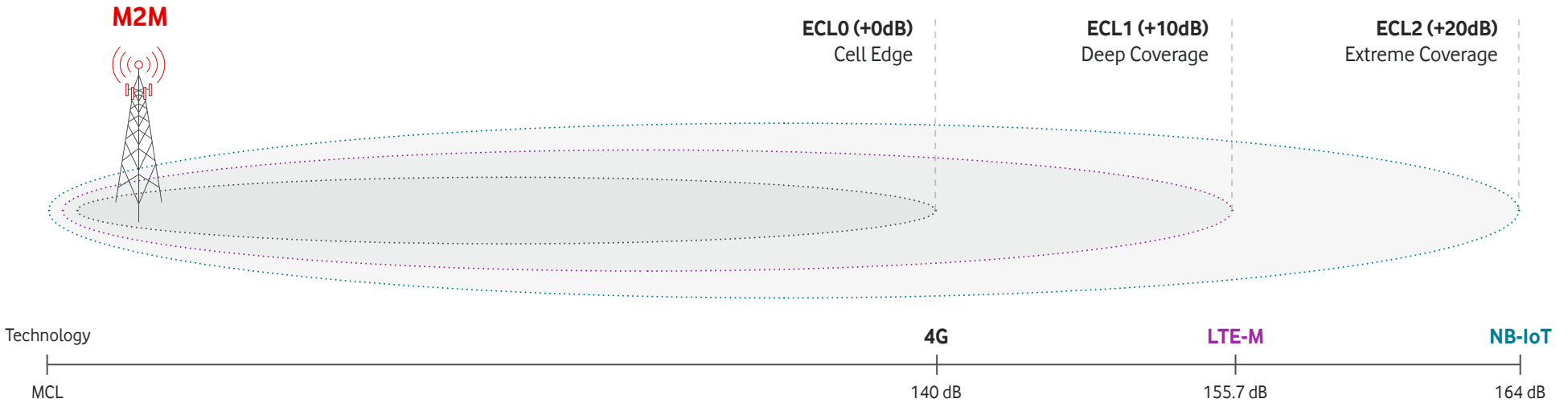
1.4 Coverage class comparison

As mentioned earlier, one of the main features concerning LPWA technologies is the enhanced coverage capability, this is contributed to the maximum coupling loss (MCL), which is defined as the maximum channel loss between a UE (user equipment), in this example an LPWA device, and the eNodeB at which the signal can withstand or tolerate in an environment and still be delivered at a good receiver level. In other words, the higher the MCL the more robust is the technology and the further it can be transmitted. For LTE-M the MCL has a calculated 10dB gain when compared to legacy LTE, while in the case of NB-IoT there is a 20dB gain. This allows for deep coverage provided by LTE-M and extreme coverage in underground and remote areas for NB-IoT.



Based on our previous testing NB-IoT has the ability to penetrate two to three double brick walls, enabling connectivity in underground car parks and basements.

(Note +10dB approximately equates to one brick wall)



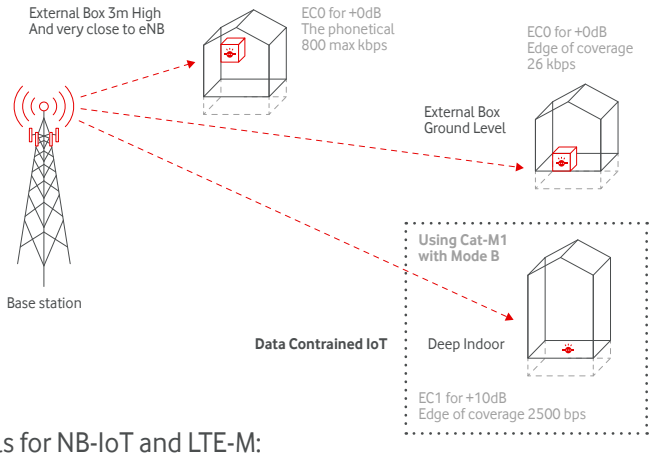
1. Introduction to NB-IoT and LTE-M usage and application

The MCL gains for LTE-M and NB-IoT are attributed to certain factors, which are based on the following:

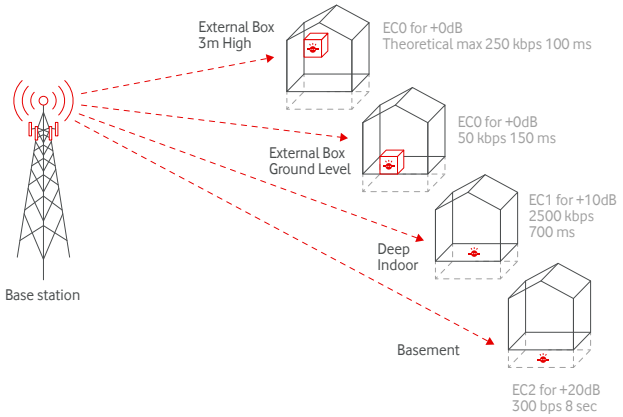
- Repetition of transmissions
- New control channels (usage of Non Access Stratum)
- Size of UE bandwidth

When in coverage classes ECL1 and ECL2, there can be quite a delay in attaching, synchronizing and sending a tracking area update. The throughput levels can also be affected based on which coverage level you are in.

Cat-M1 Application Radio Signature (in build mode)



NB-IoT Application Radio Signature (in build mode)



Summary of typical throughput, latency and synchronization levels for NB-IoT and LTE-M:

Coverage Class	NB-IoT Down Link	NB-IoT Up Link	LTE-M Down Link	LTE-M Up Link	Sync	Latency
EC0 +0dB	~ 20-250 kbps	~ 50-250 kbps	~ 800 kbps	~ 600 kbps	~ 100 ms	~ 100-150 ms
EC1 +10dB	~ 4000 bps	~ 2500 bps	~ 300 bps	~ 300 bps	~ 300 ms	~ 500-700 ms
EC2 +20dB	~ 450 bps	~ 300 bps	*x	*x	~ 3 sec	~ 7-8 sec

*No ECL2 coverage available with LTE-M
Synchronisation values shown here is the instance for when a PDP context has already been established

2. Device development

Guidance and suggestions are provided within this section to assist in implementing NB-IoT and LTE-M in a live environment, which should contribute to improving the device behaviour of an MTC type UE in a live or test environment. While extreme forethought has been given so as to include items which should be initially considered, no two use cases are the same, and so we do recommend to discuss matters of live implementation and expected device behaviour with your local IoT Solution Architect.

2.1 Items to highlight

It is advisable that a developer has a good understanding of NB-IoT and LTE-M. The proceeding items should assist in the application design and provide a good starting point for things to consider and implement which can be used to help design an optimised device behaviour in a live environment.

- Carefully consider the use case of the device, NB-IoT is more ideal for very sleepy, less “chatty” devices which send small amounts of data, separated by long periods where no comms is required.
- Build applications that can effectively operate with a data-constrained communication IoT model. This will help to enhance the performance of your device and allow for better interaction with RANs in different markets.
- MTC devices have a lower access priority in relation to standard mobile devices, and LPWA has delay-tolerant access behaviour and so an application developer needs to build a delay-tolerant application to support this type of device behaviour.
- Complete multiple field and lab trials where possible and record your observations. If there are plans to deploy in multiple networks in different markets, then field trials for all the different markets and networks should be undertaken.
- Ensure you know which networks you are planning to deploy your devices; there is a variation of frequencies being used by the markets. It is difficult for a one antenna/device to fit every market.
- Greatly consider the antenna design including the deployment environment. Seeking assistance from a professional expert can address any major concerns.



2. Device development

- Consider whether using a Private APN or Shared APN. A Shared Public APN will give a reduced feature set, and a private APN has some SLAs.
- Try to use efficient lightweight LPWA-appropriate protocols such as UDP, LwM2M, CoAP etc.
- Incorporating and considering the available network features for enhanced service can prove to be very beneficial, especially those which help with battery longevity on an LPWA device. These are features like PSM, eDRX, RAI and High Latency Communications (HLComms).
- Consider using PSM with SIM suspend, this type of deep sleep mode will help with reducing the power consumption leading to longer battery life. Note that while the device is in deep sleep mode, it cannot be woken up remotely.
- Do a thorough review to consider the choice of module based on your requirements.
- Consider the following:
  - Band support
  - Integrated devices
  - Accreditations / device certifications
  - Device continuous support
- If your developers are planning to complete device updates or FOTA in the future, please inform your local IoT Solution Architect about this; consider a distributed update.
- Include considerations for how to update device firmware:
  - Firmware over the Air (FOTA)
  - Delta engine - update model, only transferring changes
  - Consider using Blockwise Transfer utilising CoAP or LwM2M



2. Device development



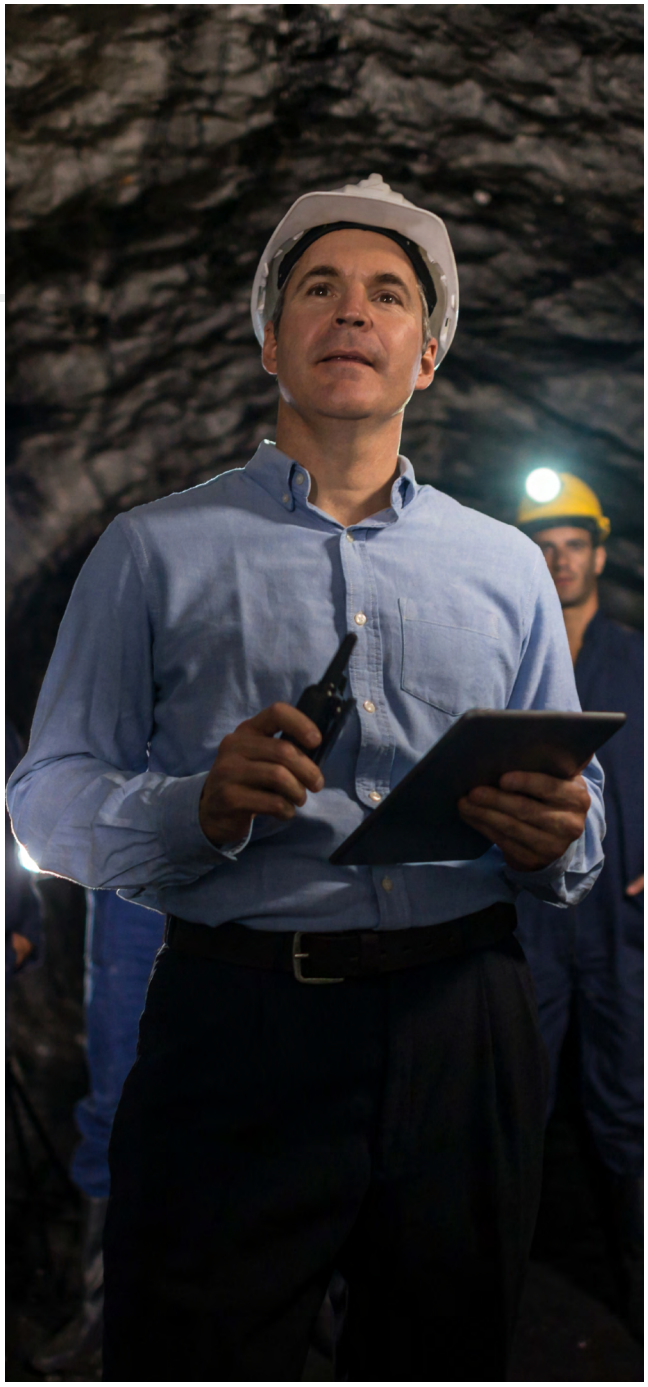
2.2 Items to flag in design considerations

Due to the complexity and intrinsic behaviour of NB-IoT and CAT-M1devices, great consideration should be given to avoid using protocols or capabilities which could impede and greatly affect the device behaviour and battery life when managing the design considerations. Listed within this section are items which could negatively impact device performance if the guidance is not followed.

- Try avoiding the usage of protocols or capabilities that encapsulate or utilise a tunnel over TCP. For example: WITS, DNP3, HTTP, HTTPS, MQTT (this list is not exhaustive). These application layer protocols sometimes do not perform very well in extreme coverage scenarios without a customised TCP stack (at both ends). This would most likely have a negative impact on your battery life.
- Try avoiding power cycling your device, especially if you are planning to send data more frequently than once a week. This inadvertently forces the device to search, re-register and re-open a new PDP context, ultimately using more power than keeping the device in PSM state; this is hugely battery inefficient.

2. Device development

- Constantly closing and reopening your PDP session for every transmission would not make for an ideal design, especially as Vodafone's billing system assumes 1kB of traffic for every attach using internet APNs. Different markets will also implement different timings for their extended TAU timers and PGW timers, and the PDP context maximum timer can also vary. Please retrieve the latest information from your local IoT Solution Architect for the markets where there is a plan to deploy.
- Try to avoid using protocols that generate lookup types of traffic i.e DNS. We recommend using private cloud services. If using public cloud, a request will need to be made to the cloud provider for static IP addresses. Please take extreme care if considering the use of Elastic IP addresses.
- Trying to consider an LTE-M implementation for full streaming capability is highly unadvised, as well as high bandwidths, time-critical (real-time) data and mission-critical (real-time) data usage. An LTE-M service will not be provided with the same speed and priority service as legacy 4G/LTE.
- Utilising NB-IoT for time-critical and mission-critical data is something our technical experts advise against and should be avoided. Should an NB-IoT device be in a power saving state, for example PSM, it can only be woken by direct external stimuli and not by paging from the network. In addition, if the device is in enhanced coverage class 2 (ECL2) or deep coverage, then it might take a longer period to transmit an update.
- NB-IoT has high latency, and if a device utilises and requests too many resources, it can have a negative impact on other devices on the same local cell of the eNodeB. This could lead to restrictions being placed on the local network being used by that cell or even that specific IMSI.
- In some situations where the network goes into congestion, the eNodeB might assign the LPWA device an extended wait timer which can be between 1sec-1800 secs (30 mins maximum) in duration based on 3GPP Rel13; this is being extended to a maximum of 4096 secs in later releases. Considerations should be made to reduce transmission frequency to minimise and manage these scenarios.



3. Conclusion

3.1 Summary and final notes

In concluding this paper, our technical experts have provided some final considerations and closing comments.

- If any of the guidance in section 2 highlights and identifies that multiple design changes might need to be reviewed, it is recommended that the impact be assessed with a reconsideration if the device will perform as expected, and possibly reach out to your local IoT Solution Architect with your concerns.
- A less costly device might not fulfil the requirements for a developer's use case. A more costly device might be better suited, especially if deployment will be in different markets. Review the device specifications.
- Do complete intensive research concerning the antenna that you require for your device, this should be based on the environment, location and the type of "device mounting" you would like to implement.
- For LPWA, a data-constrained application design should be implemented, due to the niche network characteristics.
- When using public or private cloud services, please discuss this with your local IoT Solution Architect.
- Complete trials within the RANs for the markets where you are planning to install and deploy your devices. There are different network vendors and settings being utilised for the available RANs offering LPWA coverage.
- NB-IoT was designed for small, infrequent amounts of data. Some markets have separate recommendations for data throughput levels, please speak to the local IoT Solution Architect concerning this.
- An LTE-M service will not be provided with the same speed and service as legacy 4G/LTE and will need to be considered as separate technologies with separate APNs for any multibearer design.
- Utilise our Vodafone IoT Device Test and Support Services where this is possible.
- Invest in tracking tools such as Wireshark and XCAL. This will assist in device troubleshooting.
- We offer various Professional Services packages to assist with design considerations for LPWA including that for antenna design.

If you are uncertain of any items as listed above in this document, it is advisable to reach out to your local IoT Solution Architect who will discuss this with a subject matter expert at Vodafone. You can also speak to your account manager or send an email to **iot@vodafone.com**.

Please visit **www.vodafone.com/iot** for more information concerning LPWA and for more information concerning Professional Services, please visit **www.vodafone.com/business/iot/professional-services**

3. Conclusion

3.2 Appendix

GLOSSARY OF TERMS

3GPP – Third Generation Partnership Program

CAT-M/M1 – Category Machine Type Communication (see LTE-M)

CAT-NB/CAT-NB1/CAT-NB2 – Category Narrowband, Narrowband Release 1, Narrowband Release 2

CPU – Central Processing Unit

CoAP – Constrained Application Protocol

DNP3 – Distributed Network Protocol 3 (DNP3)

DNS – Domain Name Server

EC-GSM IoT – Extended Coverage Global System for Mobile Communication Internet of Things

ECL – Enhanced Coverage Level

eDRX – extended Discontinuous Reception

eNodeB – enhanced NodeB

FOTA – Firmware Over The Air

GSM – Global System for Mobile Communications

GSMA – Global System for Mobile Communications Association

IoT – Internet of Things

LPWA/LPWAN – Lower Power Wide Area/Low Power Wide Area Network

LTE-M – Long Term Evolution Machine Type Communication

MQTT – Message Queuing Telemetry Transport

MTC – Machine Type Communications

MTU – Maximum Transmission Unit

NB-IoT – Narrowband Internet of Things

PDN – Packet Date Network

PDP – Packet Data Protocol

PGW – Packet Gateway

PSM – Power Save Mode

RA/RAI – Release Assist / Release Assist Indicator

SLA – Service Level Agreement

TCP – Transmission Control Protocol

UE – User Equipment

UDP – User Datagram Protocol

WITS – World Industry Telemetry Standard Protocol

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