NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

CZ4023 Advanced Computer Networks
Project Assignment

New applications enabled by 5G cellular networks

Name: Goh Zongye Benjamin
Matric No: U2022728L

Abstract

With the advent of 5G (Generation) cellular networks, many new technologies have been created alongside which would be unfeasible with the previous 4G specifications. This paper will look into various technologies built for 5G, their many new applications introduced and analyse how they work.

Introduction

Within the last 4 decades there has been rapid growth in wireless mobile communication, from 1G to 4G prioritising voice transmission to usable speeds [1]. Now with 5G introducing low latency and fast speeds it has been adopted by a wide range of industries and individuals, with a 56% estimated penetration rate by 2025 [2].

As the generations of mobile communication evolves it utilises more and more bandwidth, an increase in frequency domain, and with advancements in mobile processing speed, higher resolution digital modulation schemes can be used to increase transmission rates through an increase of possible combination of the received analog signal [3].

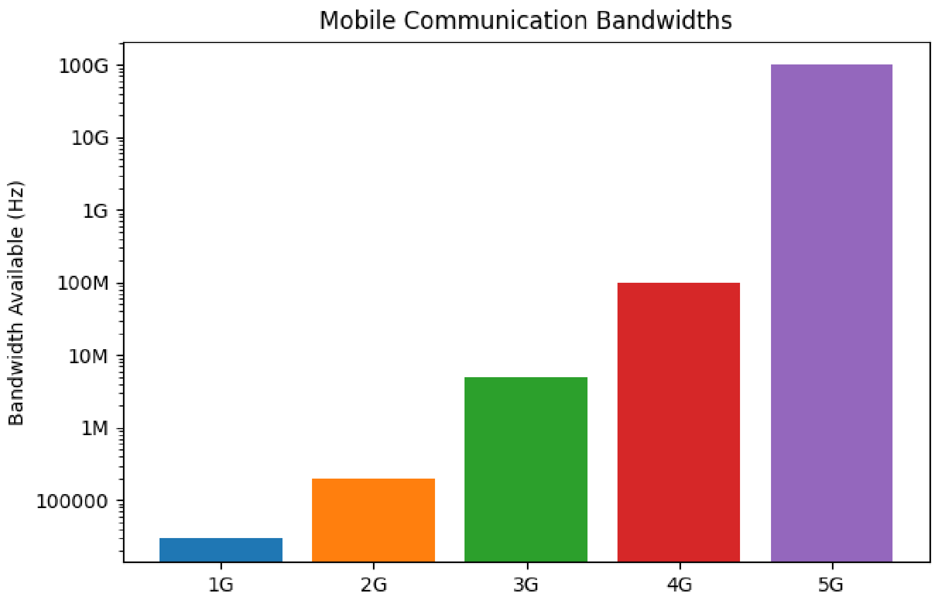

Figure 1: Increase in Analog Bandwidth

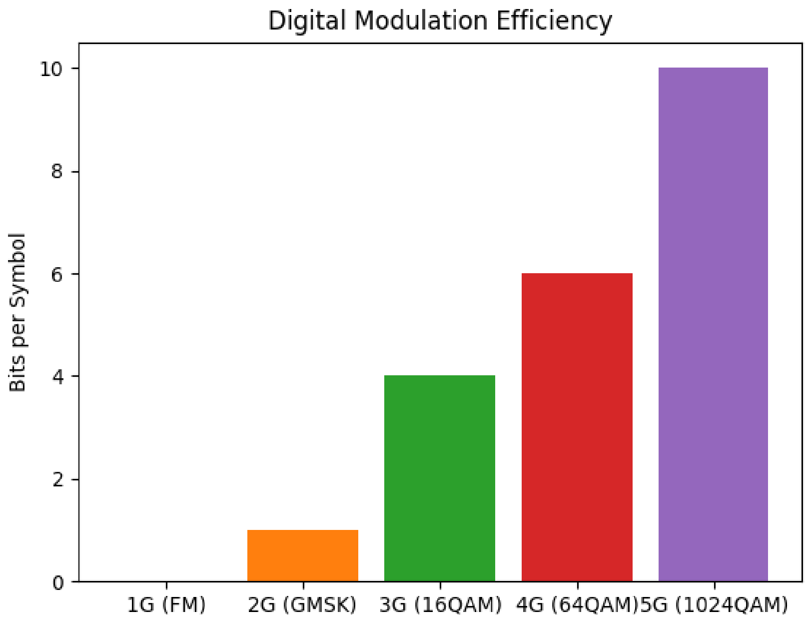

Figure 2: Advancement in Digital Modulation

With the development of 5G, its core network, which manages voice and data communications, has been integrated with the internet, cloud services and distributed servers, decreasing latency between them. Most importantly, Network Slicing and Network Function Virtualization (NFV) is introduced with 5G which allows different types of services to be allocated to users. [4]

Network Slices has mainly been categorised into 3 main services, with each designed to handle specific types of applications and use cases.

First, Enhanced Mobile Broadband (eMBB) delivers significantly higher data rates and capacity to mobile and fixed wireless broadband users. It supports applications that require high download and upload throughput such as High-Definition (HD) video, live Augmented Reality (AR) and live Virtual Reality (VR) streaming [5].

Second, Ultra-Reliable Low Latency Communication (URLLC) was made for cases where low latency/fast response times and reliability are critical. It supports applications that cannot tolerate errors and packet loss such as autonomous vehicles, remote surgery and industrial automation [5].

And last, Massive Machine Type Communication (mMTC) was designed to support a massive number of low power devices, usually associated with the Internet of Things (IoT). It supports seamless connectivity between IoT devices such as sensors, infrastructure and monitors so they can work together harmoniously.

Network Function Virtualization

In traditional networking, functions such as routing, switching and firewalls are each implementing using dedicated and specialized hardware. Having such tightly-coupled hardware and software made them difficult to scale. [6] With NFV, generic computer equipment could be used to emulate the dedicated hardware, allowing for easier scalability and at lower cost.

Compared to 4G, which uses specialized hardware, is unable to adapt well to the network when there are changes in demand of services. 5G however, with NFV, allows services to be swapped out on demand, allowing operators to create network slices tailored for specific scenarios.

The switch to NFV is not completely free of troubles. With the switch to generic hardware, power and performance efficiency will be dropped due to virtualization overhead, it could be a new attack vector for potential malware and an effective orchestrator must be implemented to fully utilize NFV.

Network Slicing

Each network slice is its own isolated virtual network and is configured to follow the requirements of the corresponding 5G service such as connectivity, speed and capacity. This allows the 5G network to support a wide range of applications with their own specific requirements.

In the healthcare setting for example, network slicing can be crucial to support a large variety of application; From media handling, data protection and data analysis. [7]

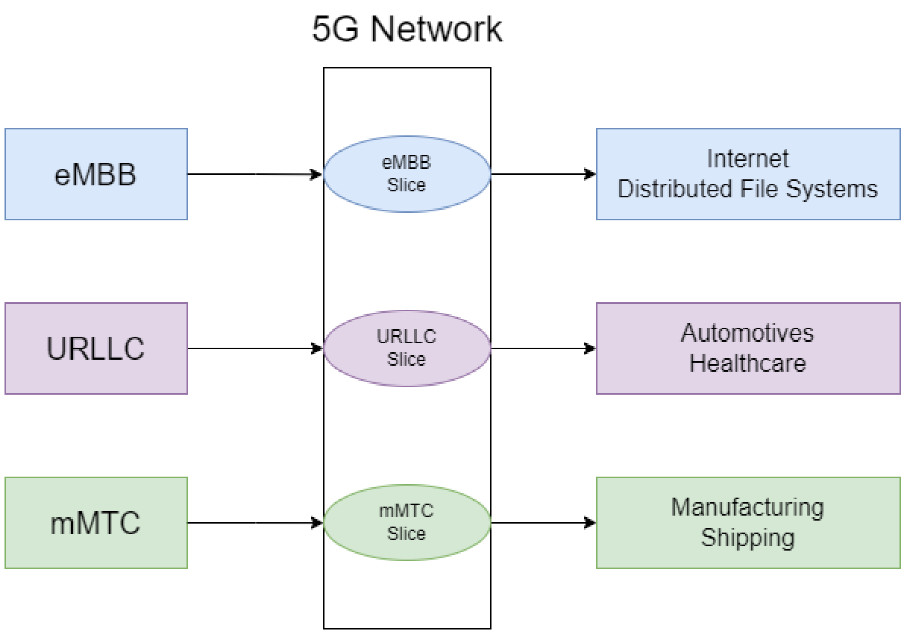

Figure 3: Diagram of Network Slice and Use Cases

Enhanced Mobile Broadband (eMBB)

eMBB is the general advancement, from 3G and 4G, in mobile broadband which is what most people would think of mobile networking. With eMBB, it implements faster connection, throughput and capacity with data rates peaking at 10 Gbps and mobility supported up to 500km/h. [8]

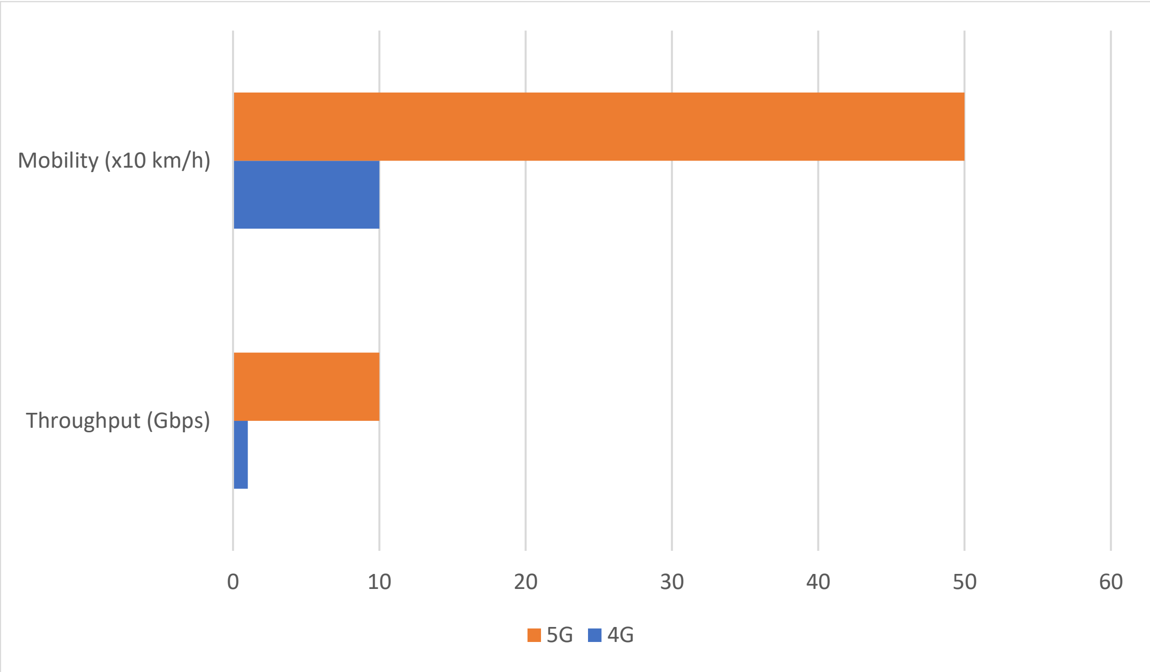

Figure 4: 4G LTE comparison with 5G eMBB

With the 10x improvement in throughput, high-definition media will be much more accessible to a wide range of users, having them not require to wait for video packets to arrive to fill the buffer as long before it can start playing. With the large reduction in latency, VR/AR interactive applications will be feasible as a Motion-to-photon (MTP) latency of 20ms or lower must be met to prevent nausea [9], which was unsustainable with 4G's average of 30ms latency.

eMBB also has enhanced spectral efficiency through the use of beamforming techniques and Massive Multiple Input, Multiple Output (MIMO).

In Massive MIMO, base stations and devices may have hundreds of antennas compared to up to 8 in 4G which allow multiple copies of the radio signal to be transmitted and received, all being slightly different due to noise, path loss and multipath propagation. The received signals can be used to improve the quality of the final signal by finding out the errors between each received signal. The technique is known as spatial diversity as the antennas are spatially separated from one another. With the increase in antennas, it also allows increased capacity as several transition paths can be used as channels for signal carriers.

With beamforming it focuses the radio signal in the direction of the user rather than broadcasting it in its coverage radius, enhancing signal quality and reducing wireless collisions.

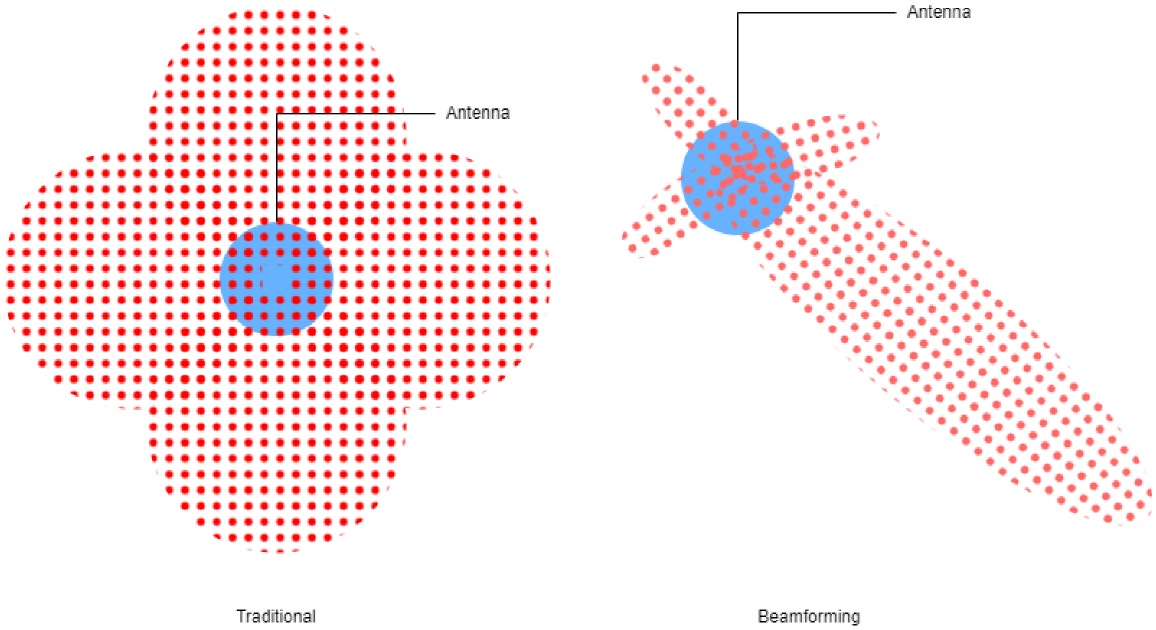

Figure 5: Traditional vs Beamforming Radio Transmission

With the advancements made in eMBB, new use cases as broadband access in high-speed transportation such as buses/trains and smart offices can see light. For smart offices specifically, its increased network speed could be used for high-definition video transfer from a wireless camera, AR/VR use from employees or general high traffic mobile application services. With 4G LTE, it would not have been available due to the sheer bandwidth requirement and traditional lack of base stations installed in office spaces. [10]

Ultra-Reliable Low Latency Communication (URLLC)

URLLC is designed to provide wireless communication at extremely low latencies and high reliability. With a promise of end-to-end latency of 1ms and greater than 99.999% reliability, it widely used in real-time applications. URLLC typically operates in 410MHz to 7.125GHz and 24.45GHz to 52.6GHz, the higher frequency range offering substantially better performance and data rates.

Multiplexing is also used to reduce latency, specifically Time Division Duplex (TDD) and Frequency Division Duplex (FDD). TDD allocates each user a specific timeslot where they are allowed transmission and FDD allocates each user a frequency band for transmission. With multiplexing, multiple users are able to transmit and receive simultaneously, preventing slower transmissions from causing delays thus reducing overall latency.

URLLC also takes advantage of edge computing to reduce the physical distance the data is required to travel as compared to router to a traditional server, further decreasing latency. [11]

To achieve reliability, URLLC duplicates packets and simultaneously transfers them to the receiver via 2 separate user plane paths. Redundant packets will be discarded if the original was received successfully on the receiver side. Using redundancy, service failure can be avoided where the packet is lost in one path or if the path exceeds the upper bound of the latency requirement. [12]

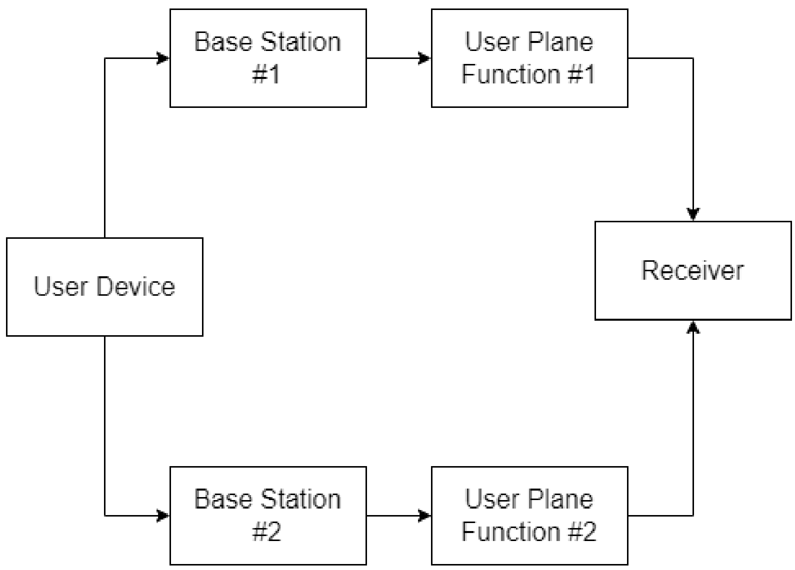

Figure 6: Diagram of Redundant Data Pathing

With the addition of URLLC in 5G, emerging applications such as autonomous driving, driver assisting applications and remote surgery can be realized. All 3 require as little latency as possible due to their reactive nature to unexpected actions and also requires the upmost reliability so actions made by user or devices will not be lost due to their importance.

Autonomous driving for example can establish connections with other nearby vehicles for a Vehicle-to-Vehicle (V2V) direct communication and update one another of their positions, speed and acceleration. Such communications require over-the-air latencies of single digit milliseconds and maximum packet reliability is a must as well. [13]

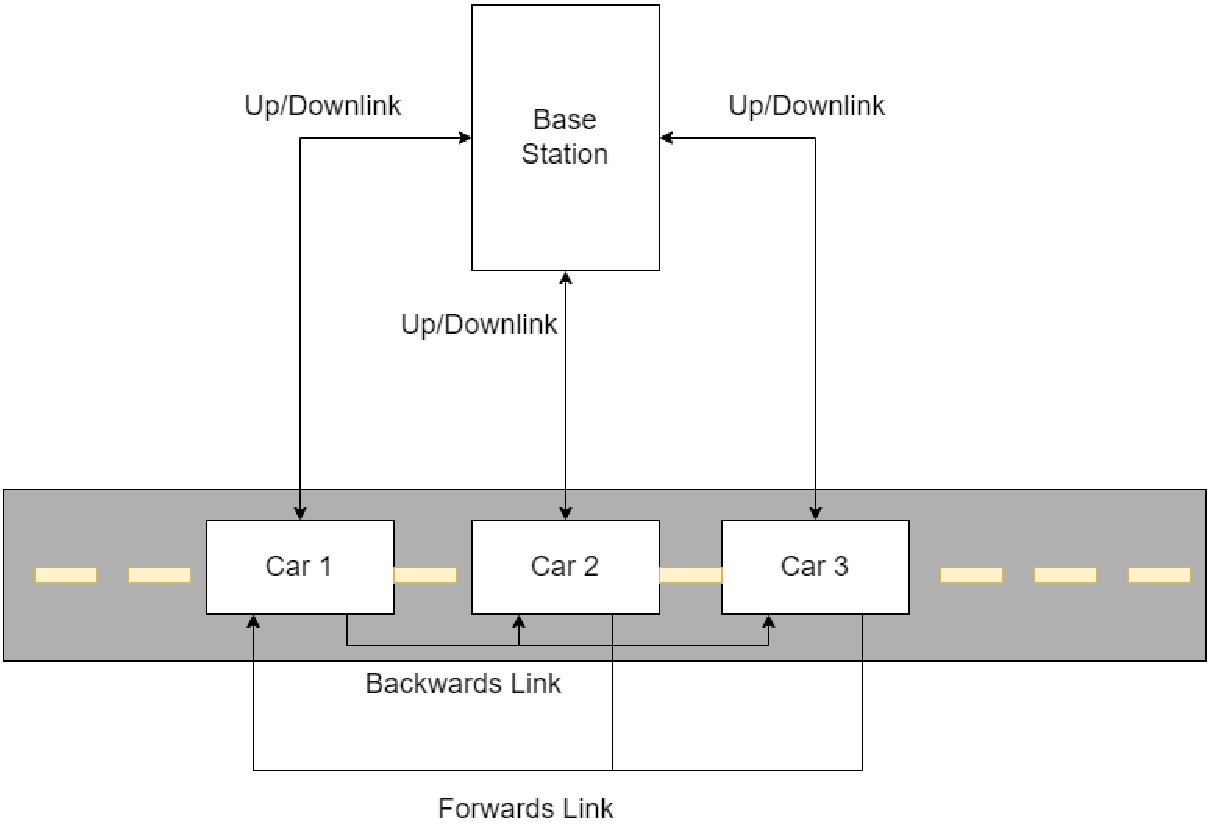

Figure 7: Diagram of Autonomous Vehicle V2V Communication

Massive Machine Type Communication (mMTC)

Unlike the previous 2 services, mMTC aims to provide an efficient and highly scalable communications platform for a large number of devices which make up the Internet of Things (IoT), with targets of up to hundreds of thousands of devices per square kilometre, enabling the future of smart cities. [14]

The main challenges of mMTC include the sheer number of devices which will be required to maintain an active connection with. As the number of devices increase, the service must be able to efficiently manage the traffic to and from all of the devices. To effectively manage the devices, mMTC uses Non-Orthogonal Multiple Access (NOMA) multiplexing instead of Orthogonal Frequency-Division Multiple Access (OFDMA) which eMBB and URLLC uses. NOMA allows multiple devices to share the same time-frequency resources, allowing for simultaneous transmissions which results in an improved spectral efficiency compared to OFDMA, where users share only the bandwidth. [15]

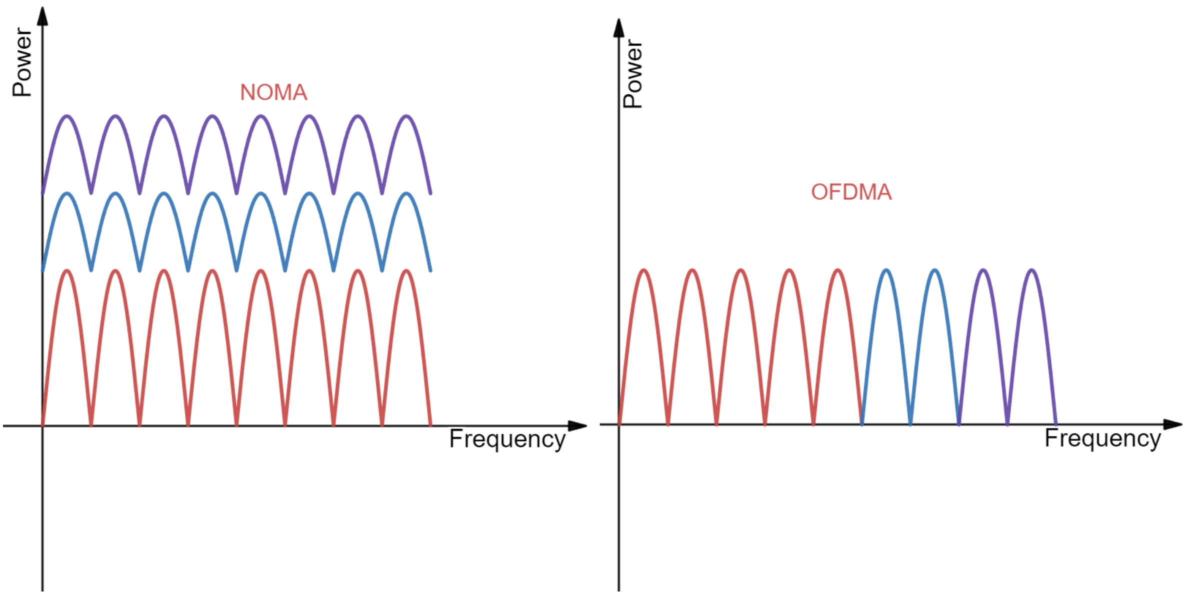

Figure 8: Comparison of NOMA and OFDMA Spectrum

Another challenge is managing the energy efficiency of IoT devices, especially those on battery power. The nature of mMTC use cases often includes devices stationed in remote or hard to reach areas such as sensors built into infrastructure or on a high wall, which makes battery replacement or charging non-feasible most of the time. mMTC addresses this by decreasing packet size transmitted by IoT devices so their design complexity can be simple and low power. In addition, Narrowband IoT (NB-IoT) is used as a lower-power wide-area network (LPWAN) protocol which significantly reduces transmission power from 23dBm to 14dBm with the trade-off of increased latency and lower transmission speeds.

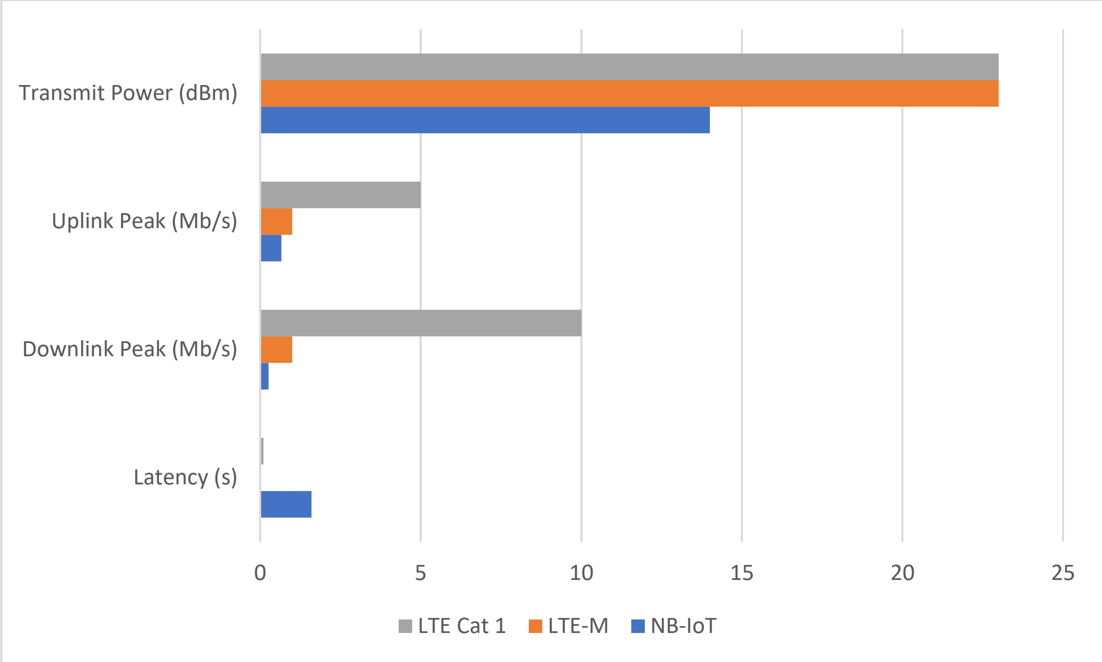

Figure 9: Comparison of LPWAN standards

The trade-off is accepted as the small packet sizes do not require high up/downlink and the information transmitted is not treated as time sensitive.

New applications from mMTC focus on industrial applications such as smart cities or improving industrial logistics and efficiency.

A way mMTC can be used in smart cities is smart metering of resources. To maximize resource utilization in smart cities, smart meters can take periodic readings and use the data to find peak usage or trends. The data can then be used to optimize future resource allocation. An example would be for gardening, if the city is full of plants which have automated water dispersion, collecting the water used and soil hydration could determine a proper time or location for dispersion.

Conclusion

The adoption of 5G networks marks a transition into a new era of wireless communication, with many new applications and possibilities being unlocked. eMBB revolutionizes the way we use high-speed internet, providing heavily improved data rates and media streaming experience. URLLC now allows mission critical applications with strict latency and reliability requirements to be feasible and adopted in healthcare and autonomous devices. Lastly, mMTC further improves the structure for IoT, connecting an unprecedented number of devices and paving the way for smart cities and transportation.

5G cannot be treated as simply an evolution from 4G LTE, it offers much more and is the start of a technological revolution. The timeline of 5G is still fresh, with much more advancements in hardware design and software algorithms ahead to greatly improve what we have available currently.

[1] M. R. Bhalla and A. V. Bhalla, ‘Generations of Mobile Wireless Technology: A Survey’, *Int. J. Comput. Appl.*, vol. 5, no. 4, pp. 26–32, Aug. 2010, doi: 10.5120/905-1282.
[2] G. F. Huseien and K. W. Shah, ‘A review on 5G technology for smart energy management and smart buildings in Singapore’, *Energy AI*, vol. 7, p. 100116, Jan. 2022, doi: 10.1016/j.egyai.2021.100116.
[3] O. T. Eluwole, N. Udoh, M. Ojo, C. Okoro, and A. J. Akinyoade, ‘From 1G to 5G, What Next?’, 2018.
[4] P. K. Chartsias *et al.*, ‘SDN/NFV-based end to end network slicing for 5G multi-tenant networks’, in *2017 European Conference on Networks and Communications (EuCNC)*, Jun. 2017, pp. 1–5. doi: 10.1109/EuCNC.2017.7980670.
[5] B. S. Khan, S. Jangsher, A. Ahmed, and A. Al-Dweik, ‘URLLC and eMBB in 5G Industrial IoT: A Survey’, *IEEE Open J. Commun. Soc.*, vol. 3, pp. 1134–1163, 2022, doi: 10.1109/OJCOMS.2022.3189013.
[6] R. Roseboro, ‘White Paper: Using Hardware to Improve NFV Performance’, 2015.
[7] H. Jain, V. Chamola, Y. Jain, and Naren, ‘5G network slice for digital real-time healthcare system powered by network data analytics’, *Internet Things Cyber-Phys. Syst.*, vol. 1, pp. 14–21, 2021, doi: 10.1016/j.iotcps.2021.12.001.
[8] H. Yu, H. Lee, and H. Jeon, ‘What is 5G? Emerging 5G Mobile Services and Network Requirements’, *Sustainability*, vol. 9, no. 10, Art. no. 10, Oct. 2017, doi: 10.3390/su9101848.
[9] A. Hazarika and M. Rahmati, ‘Towards an Evolved Immersive Experience: Exploring 5G- and Beyond-Enabled Ultra-Low-Latency Communications for Augmented and Virtual Reality’, *Sensors*, vol. 23, no. 7, p. 3682, Apr. 2023, doi: 10.3390/s23073682.
[10] J. Zhang, ‘Design of smart campus construction scheme supported by 5G technology’, in *The International Conference on Forthcoming Networks and Sustainability (FoNeS 2022)*, Oct. 2022, pp. 445–449. doi: 10.1049/icp.2022.2476.
[11] P. Skarin, W. Tarneberg, K.-E. Arzen, and M. Kihl, ‘Towards Mission-Critical Control at the Edge and Over 5G’, in *2018 IEEE International Conference on Edge Computing (EDGE)*, San Francisco, CA: IEEE, Jul. 2018, pp. 50–57. doi: 10.1109/EDGE.2018.00014.
[12] ‘Ultra Reliable and Low Latency Communications’. Accessed: Nov. 24, 2023. [Online]. Available: https://www.3gpp.org/technologies/urlcc-2022
[13] M. Mikami, K. Serizawa, Y. Ishida, H. Nishiyori, K. Moto, and H. Yoshino, ‘Field Experimental Evaluation on Latency and Reliability Performance of 5G NR V2V Direct Communication in Real Express Highway Environment’, in *2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring)*, Antwerp, Belgium: IEEE, May 2020, pp. 1–5. doi: 10.1109/VTC2020-Spring48590.2020.9129379.
[14] M. Kamel, W. Hamouda, and A. Youssef, ‘Uplink Coverage and Capacity Analysis of mMTC in Ultra-Dense Networks’, *IEEE Trans. Veh. Technol.*, vol. 69, no. 1, pp. 746–759, Jan. 2020, doi: 10.1109/TVT.2019.2954233.
[15] Z. Zhang, H. Sun, and X. Lei, ‘Non-orthogonal Multiple Access’, 2018, pp. 1–4. doi: 10.1007/978-3-319-32903-1_57-1.