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5G Slicing for C-V2X Communications

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3GPP, 5G, C-V2X, V2X, cooperative driving, vehicles platooning, advanced driving, extended sensors, remote driving

1 5G SLICING INTRODUCTION

Before explaining the fifth-generation networks (5G) slicing, we will take this opportunity to provide you with some background information about 5G and all the hype that goes with it. First of all, 5G is the next generation of mobile broadband that will hit the market in 2020. Remember there was first 2G (i.e., GSM), 3G, and then came 4G. With 5G, you should be able to have high reliability for critical communication services (i.e., health & wellness, cooperative driving, factory automation), low latency to provide fast response time for devices to communicate and interactivity of services (i.e., AR/VR, remote driving, factory automation, electrical power distribution), low power consumption for connected things (i.e., IoT) to operate for a longer period of time (i.e., months or years), and faster speeds (i.e., >1 Gbps for downloads). Figure 1 shows examples of 5G driver attributes.

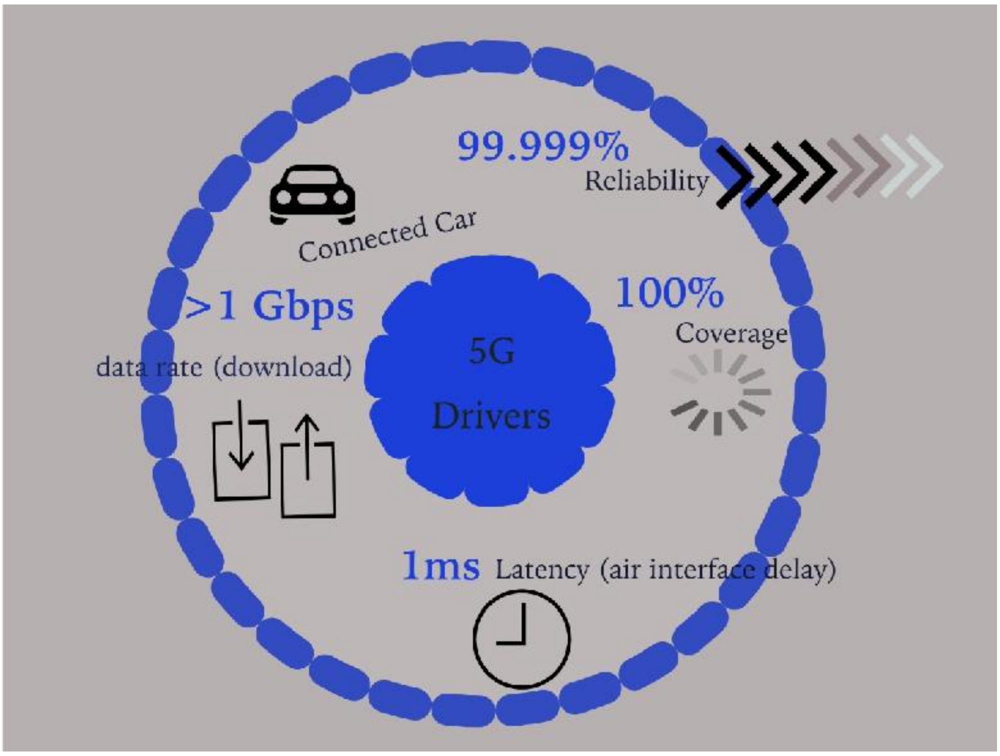

Figure 1: Examples of 5G driver attributes

Frist, what is a network infrastructure? It is the hardware and software resources of a whole network that allow network connectivity (e.g., so that network services are able to allow devices to connect with each other), communication (e.g., so that network services are able to allow devices to communicate with each other), operations and management of the network. Moreover, the network infrastructure provides the communication path and services between users, processes, applications, services and external networks (i.e., internet). Second, what is a slice? A slice is a piece that have been separated from something larger. Now, if we think about those two definitions, we can begin to understand the meaning of network slicing. In short, it means the whole network is sliced in pieces. In other words, these slices are used to partition the network. In terms of 5G network slicing, it allows the network infrastructure to be sliced (partitioned) into multiple virtual networks. This sets the stage for the virtual networks to be flexibly configured to meet specific requirement of customers, applications, services, devices, and others. Since there are many 5G use cases with different requirements in relation to functionality, network slicing can be an enabler for supporting the multitudes of use cases.

2 5G SLICING USE CASES AND SERVICES

A virtual network slice is an independent logical network that can support the requirements of a use case. The slices are isolated from each other such that one slice can interfere with another slice. This means that a slice can be defined based on functions. These functions can be based on latency, reliability, coverage, data rate, connectivity as well as capacity.

A virtual network slice can be configured for virtual reality/augmented reality (AR/VR) use cases, collaborative gaming use case, cooperative driving use case, factory automation use cases, health & wellness services, remote driving use case, internet-of-things (IoT) use cases, electrical power distribution services, and other use cases and services. An example in shown in Figure 2.

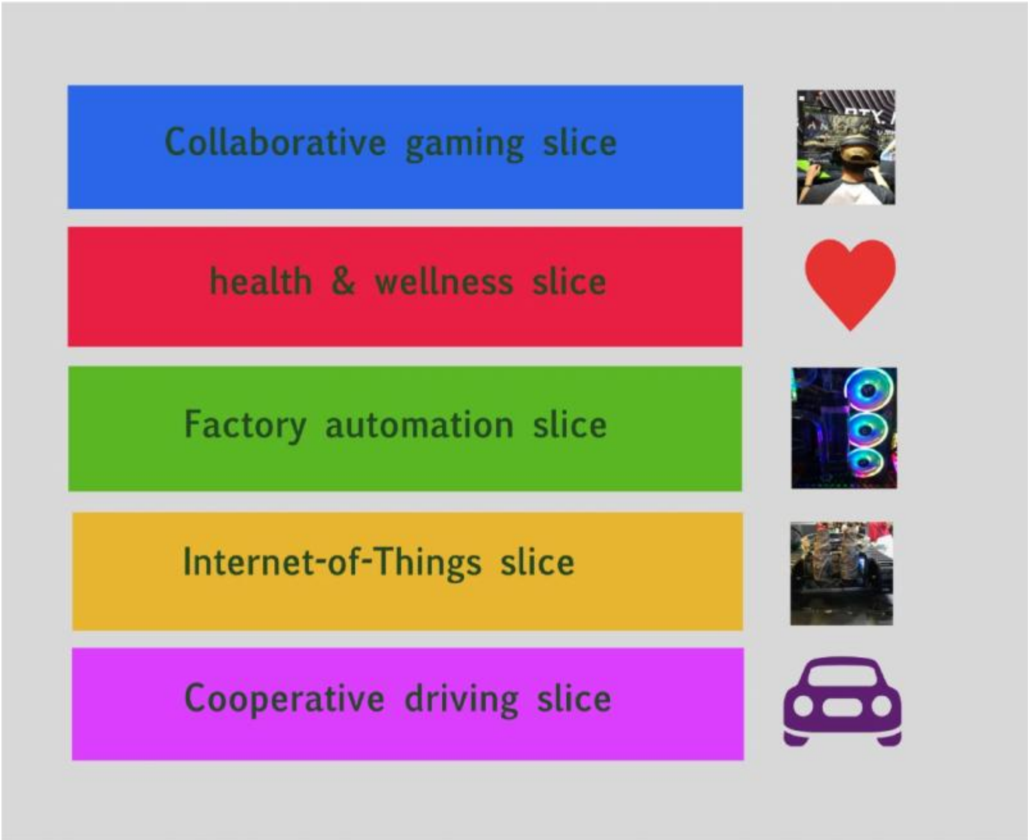

Figure 2: Examples of 5G network slices based on use cases

Collaborative gaming encourages players to actively collaborate. It gives the players the opportunity to share their knowledge and experience with other players and to collaborate together in order to complete a task. This allows collaborative games to be used as a tool for creative thinking and brainstorming for problem solving. This means it can be used as game-based learning and team building as well as other uses. An example of collaborative gaming is shown in Figure 3.

Figure 3: Examples of collaborative gaming

However, this is not the total list as there are other industries that can use network slicing that are provided in Table 1. The industrial internet of things (IIoT) is different from other IoT services because the focus is more on connecting machines and things (devices). There is a wide range of potential use cases for IIoT that includes smart factory, transportation monitoring, smart farming, manufacturing equipment monitoring, environmental monitoring, asset performance management and the list goes on and on. One of the interesting aspects of IIoT is that it has a much longer service usage that calls for low power consumption so that it last years.

Table 1: Industries that could take advantage of network slicing

Industry	Potential	Benefiter
Automotive	High	Consumers
Health & Wellness	High	Consumers
Industrial Internet of Things (IIoT)	High	All
Media & Entertainment	High	Consumers
Gaming	High	Consumers
Smart Cities	Medium	Stakeholders
Logistics	Medium	Stakeholders
Utilities	Medium	Stakeholders
Financial	Low	Stakeholders

3 5G SLICING FOR C-V2X COMMUNICATIONS

Cellular Vehicle-to-Everything (C-V2X) encompasses V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network), V2P (Vehicle-to-Pedestrian), and V2V (Vehicle-to-Vehicle) communications for Intelligent Transport Systems (ITS) applications. The use cases described for C-V2X includes vehicles platooning, advanced driving (cooperative driving), extended sensors, and remote driving. The vehicles platooning use case dynamically forms a group of vehicles travelling together at short inter-vehicle distances. The advanced driving (cooperative driving) use case enables vehicles to share local sensor data in which vehicles automatically communicate to provide driving intentions with vehicles in proximity, which helps with the coordination trajectories and maneuvers. The extended sensors use case is used to exchange raw or processed sensor data for sharing among vehicles to create collective situational awareness. The remote driving use case allows a remote driver or a cloud application to operate the vehicle, which is useful for those people who are unable to drive themselves or when vehicle is in a dangerous environment.

In order for the C-V2X use cases requirements to be achieved, multiple slices are needed by the automotive industry. Moreover, the vehicle platooning use case requires ultra reliability and low transmission rate (i.e., message/sec), advanced driving (cooperative driving) use cases require ultra reliability and low latency communications (URLLC) and low transmission rate (i.e., message/sec), remote driving use case requires ultra reliability and low latency, and extended sensors use case consist of data gathering and analysis, so, it requires ultra reliability, low latency, low transmission rate (i.e., message/sec), and high data rate. To be more precise, cooperative driving is the collection of global positioning system (GPS), light detection and ranging (LIDAR), radio detection and ranging (RADAR), cameras, of connected vehicles with intelligent information that's provided by other vehicles extended sensors that requires ultra reliability (i.e., 99.999%), low latency (i.e., 3ms), high data rate (i.e., 1 GHz), large messages exchanged, and low transmission rate (i.e., 10ms) under high connection density conditions. In Tables 2 thru and 5 we provide the use cases requirements as defined in 3GPP standards.

Table 2: Vehicle Platooning use case Requirements

Communication scenario description		Payload (Bytes)	Tx rate (Message/ Sec)	Max end-to-end latency (ms)	Reliability (%) (NOTE 5)	Data rate (Mbps)	Min required communication range (meters) (NOTE 6)
Scenario	Degree						
Cooperative driving for vehicle platooning Information exchange between a group of UEs supporting V2X application.	Lowest degree of automation	300-400 (NOTE 2)	30	25	90		
	Low degree of automation	6500 (NOTE 3)	50	20			350
	Highest degree of automation	50-1200 (NOTE 4)	30	10	99.99		80
	High degree of automation			20		65 (NOTE 3)	180
Reporting needed for platooning between UEs supporting V2X application and between a UE supporting V2X application and RSU.	N/A	50-1200	2	500			
Information sharing for platooning between UE supporting V2X application and RSU.	Lower degree of automation	6000 (NOTE 3)	50	20			350
	Higher degree of automation			20		50 (NOTE 3)	180

NOTE 1: The relative longitudinal position accuracy of less than 0.5 m for UEs supporting V2X application for platooning in proximity should be achievable.
NOTE 2: This value is applicable for both triggered and periodic transmission of data packets.
NOTE 3: The data that is considered in this V2X scenario includes both cooperative manoeuvres and cooperative perception data that could be exchanged using two separate messages within the same period of time (e.g., required latency 20ms).
NOTE 4: This value does not include security related messages component.
NOTE 5: Sufficient reliability should be provided even for cells having no value in this table.
NOTE 6: This is obtained considering UE speed of 130km/h. All vehicles in a platoon are driving in the same direction.

Table 3: Advanced Driving (Cooperative Driving) use case Requirements

Communication scenario description: Scenario	Communication scenario description: Degree	Payload (Bytes)	Tx rate (Message/Sec)	Max end-to-end latency (ms)	Reliability (%) (NOTE3)	Data rate (Mbps)	Min required Communication range (meters) (NOTE 4)
Cooperative collision avoidance between UEs supporting V2X applications.		2000 (NOTE 5)	100 (NOTE 5)	10	99.99	10 (NOTE 1)	
Information sharing for automated driving between UEs supporting V2X application.	Lower degree of automation	6500 (NOTE 1)	10	100			700
	Higher degree of automation			100		53 (NOTE 1)	360
Information sharing for automated driving between UE supporting V2X application and RSU	Lower degree of automation	6000 (NOTE 1)	10	100			700
	Higher degree of automation			100		50 (NOTE 1)	360
Emergency trajectory alignment between UEs supporting V2X application.		2000 (NOTE 5)		3	99.999	30	500
Intersection safety information between an RSU and UEs supporting V2X application.		UL: 450	UL: 50			UL: 0. 25 DL: 50 (NOTE 2)	
Cooperative lane changes between UEs supporting V2X applications.	Lower degree of automation	300-400		25	90		
	Higher degree of automation	12000		10	99.99		
Video sharing between a UE supporting V2X application and a V2X application server.						UL: 10	

NOTE 1: This includes both cooperative maneuvers and cooperative perception data that could be exchanged using two separate messages within the same period of time (e.g., required latency 100ms).
NOTE 2: This value is referring to a maximum number of 200 UEs. The value of 50 Mbps DL is applicable to broadcast or is the maximum aggregated bitrate of the all UEs for unicast.
NOTE 3: Sufficient reliability should be provided even for cells having no values in this table.
NOTE 4: This is obtained considering UE speed of 130km/h. Vehicles may move in different directions.
NOTE 5: These values are based on calculations for cooperative maneuvers only.

Table 4: Remote Driving use case Requirements

Communication scenario description	Message exchange (km/h)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)
Information exchange between a UE supporting V2X application and a V2X Application Server	250 km/h (NOTE 1)	5	99.999	UL: 25 DL: 1
NOTE 1: This is the message exchange between a UE supporting V2X application and V2X application server for an absolute speed of up to 250 km/h.				

Table 5: Extended Sensors use case Requirements

Communication scenario description		Payload (Bytes)	Tx rate (Message /Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Min required communication range (meters)
Scenario	Degree						
Sensor information sharing between UEs supporting V2X application	Lower degree of automation	1600	10	100	99		1000
	Higher degree of automation			10	95	25 (NOTE 1)	
				3	99.999	50	200
				10	99.99	25	500
				50	99	10	1000
				10	99.99	1000	50
Video sharing between UEs supporting V2X application	Lower degree of automation			50	90	10	100
	Higher degree of automation			10	99.99	700	200
				10	99.99	90	400
NOTE 1: This is peak data rate.							

If we take a look at the functionalities, we can see that ultra reliability and low latency are common requirements across the use cases that can be used to support reciprocal exchange of vehicles information, the perceived environment and intended maneuvers, as well as for data sent by vehicles to infrastructure for mapping processing of the surrounding areas (i.e. location grid of buildings and other objects) and the computed result sent in the opposite direction for extension of the spatial vehicle perception. An example of C-V2X use case is shown in Figure 4.

Figure 4: Examples of C-V2X

The channel bandwidth is dependent on the region. Furthermore, most regions use 5.9 GHz band (5.855 GHz – 5.925 GHz) or (5.850 MHz – 5.925 MHz) spectrum usage, with the exception of Japan which spectrum usage is part of the 700 MHz band (755.5 MHz – 764.5 MHz).

4 List of Standards Development Organizations

The standards development organizations (SDOs) that are listed in this document are provided in Table 6.

Table 6: Standards Development Organizations

SDO	3GPP	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Region	Europe	Japan	North America	China	Europe	North America	Korea

5 Standards Development Organizations Technical Characteristics for C-V2X Communications

There are seven SDOs that we provide information about what specific radio interface standards and technical characteristics that are used within their region for C-V2X communications. In Table 7 and Table 8 we provide a summary of technical characteristics by region side-by-side for comparison.

Table 7: List of regions Technical Characteristics of PC5 Interface

Parameter	3GPP [1]	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Operating frequency range	5 855-5 925 MHz	755.5-764.5 MHz	5 855-5 925 MHz	5 855-5 925 MHz	5 855-5 925 MHz	5 850-5 925 MHz	5 855-5 925 MHz
RF Channel bandwidth	10 or 20 MHz per channel	Less than 9 MHz	10 or 20 MHz per channel	10 or 20 MHz per channel	10 or 20 MHz per channel (10+10MHz and 10+20MHz carrier aggregation are supported)	10 or 20 MHz per channel	Less than 10 MHz
RF Transmit Power/EIRP	Max 23 or 33 dBm		Max 23 or 33 dBm	Max 23 dBm	Max 23 or 33 dBm		20 dBm
RF transmit power density		10 dBm/MHz					
Modulation scheme	QPSK SC-FDMA, 16QAM SC-FDMA	BPSK OFDM, QPSK OFDM, 16QAM OFDM	QPSK SC-FDMA, 16QAM SC-FDMA	QPSK SC-FDMA, 16QAM SC-FDMA	QPSK SC-FDMA, 16QAM SC-FDMA 64QAM SC-FDMA	64-QAM-OFDM 16-QAM-OFDM QPSK-OFDM BPSK-OFDM 52 subcarriers	BPSK OFDM, QPSK OFDM, 16QAM OFDM, 64QAM
Forward error correction	Convolutional coding and turbo coding	Convolutional coding, rate = 1/2, 3/4	Convolutional coding and turbo coding	For control channel: Tail biting convolutional coding, rate=1/8. For data channel: Turbo coding with rate up to 0.86. Rate can be controlled with a fine granularity	Convolutional coding and turbo coding	Convolutional coding, rate = 1/2, 3/4¾	Convolutional coding, rate = 1/2, 3/4
Data transmission rate	From 1.3 Mbit/s to 15.8 Mbit/s for 10 MHz channel	3 Mbit/s, 4.5 Mbit/s, 6 Mbit/s, 9 Mbit/s, 12 Mbit/s, 18 Mbit/s	From 1.3 Mbit/s to 15.8 Mbit/s for 10 MHz channel	Up to 15.8 Mbit/s for 10 MHz channel bandwidth. Up to 31.7 Mbit/s for 20 MHz channel bandwidth. Rate can be controlled with a fine granularity	From 1.3 Mbit/s to 24.5 Mbit/s for 10 MHz channel	3, 4.5, 6, 9, 12, 18, 24 and 27 Mbit/s for 10 MHz channel spacing 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s for 20 MHz channel spacing	3, 4.5, 6, 9, 12, 18, 24, 27 Mbit/s
Media access control	Centralized scheduling or distributed scheduling	CSMA/CA	Centralized scheduling or distributed scheduling	For Mode 4: Sensing with SPS, random selection. For Mode 3: eNB scheduling.	Centralized scheduling or distributed scheduling	CSMA/CA, Option: Time Slot based CSMA/CA	CSMA/CA
Duplex mode	TDD	TDD	TDD	TDD	TDD	TDD	TDD

Note [1]: Provide information about many different regions.

Table 8: List of regions Technical Characteristics of Uu Interface

Parameter	3GPP [1]	ARIB	ATIS	CCSA	ETSI	IEEE	TTA
Operating frequency range	For Rel-14 Band 3: UL: 1 710-1 785 MHz DL: 1 805-1 880 MHz Band 5: UL: 824 MHz–849 MHz DL: 869 MHz–894 MHz Band 5: UL: 824 MHz–849 MHz DL: 869 MHz–894 MHz Band 7: UL: 2 500-2 570 MHz DL: 2 620-2 690 MHz Band 8: UL: 880-915 MHz DL: 925-960 MHz Band 20: UL: 832 MHz–862 MHz DL: 791 MHz–821 MHz Band 28: UL: 703 MHz–748 MHz DL: 758 MHz–803 MHz Band 34: UL: 2010 MHz–2025 MHz DL: 2010 MHz–2025 MHz Band 39:	Not provided	For Rel-14 Band 5: UL: 824-849 MHz DL: 869-894 MHz Band 7: UL:2 500-2 570 MHz DL: 2 620-2 690 MHz Band 41: 2 496-2 690 MHz Band 71: UL: 663-698 MHz DL: 617-652 MHz	For Rel-14 For FDD UL: 1 710-1 785 MHz; DL: 1 805-1 880 MHz UL: 880-915 MHz DL: 925-960 MHz For TDD 1 880-1 920 MHz 2 496-2 690 MHz	For Rel-14 Band 3: UL: 1 710-1 785 MHz DL: 1 805-1 880 MHz Band 7: UL: 2 500-2 570 MHz DL: 2 620-2 690 MHz Band 8: UL: 880-915 MHz DL: 925-960 MHz Band 39:1 880-1 920 MHz Band 41:2 496-2 690 MHz	Not provided	Not provided

	1 880-1 920 MHz Band 41: 2 496-2 690 MHz Band 71: UL: 663 MHz – 698 MHz DL: 617 MHz – 652 MHz						
RF Channel bandwidth	1.4, 3, 5, 10, 15, or 20 MHz per channel	Not provided	1.4, 3, 5, 10, 15, or 20 MHz per channel	1.4, 3, 5, 10, 15, or 20 MHz per channel	1.4, 3, 5, 10, 15, or 20 MHz per channel	Not provided	Not provided
RF Transmit Power/EIRP	Max 43 dBm for eNB Max 23 or 33 dBm for UE	Not provided	Max 43 dBm for eNB Max 23 or 33 dBm for UE	Max 23 dBm for UE	Max 43 dBm for eNB Max 23 or 33 dBm for UE	Not provided	Not provided
RF transmit power density		Not provided				Not provided	Not provided
Modulation scheme	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	Not provided	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA, 256QAM SC-FDMA;	Uplink: QPSK SC-FDMA, 16QAM SC-FDMA, 64QAM SC-FDMA; Downlink: QPSK OFDMA, 16QAM OFDMA, 64QAM OFDMA	Not provided	Not provided
Forward error correction	Convolutional coding and turbo coding	Not provided	Convolutional coding and turbo coding	PUCCH / (Physical Uplink Control channel): Tail biting convolutional coding / Block code PUSCH / (Physical Uplink Shared channel): Turbo coding	Convolutional coding and turbo coding	Not provided	Not provided
Data transmission rate	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	Not provided	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	Max 105.5 Mbps	Uplink: From 1.4 Mbit/s to 36.7 Mbit/s for 10 MHz channel Downlink: From 1.4 Mbit/s to 75.4 Mbit/s for 10 MHz channel	Not provided	Not provided
Media access control	Centralized scheduling by eNB	Not provided	Centralized scheduling by eNB	eNB scheduling	Centralized scheduling by eNB	Not provided	Not provided
Duplex mode	FDD or TDD	Not provided	FDD or TDD	FDD or TDD	FDD or TDD	Not provided	Not provided

Note [1]: Provide information about many different regions.