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Khaledul Islam, Liang Zhang, 14th of June 2024

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Mobile Coverage Metrics

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The Canadian Radio-television and Telecommunications Commission (CRTC)
Gatineau, Quebec
Canada
K1A ON2
Tel: 819-997-0313
Toll-free: 1-877-249-2782 (in Canada only)
https://applications.crtc.gc.ca/contact/eng/library

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Abstract

This report presents a literature survey on the quality of service requirements for different types of mobile services, the required data throughput, and the required signal power level at the receivers, based on the analysis and test results conducted by industry and other international regulatory bodies.

This report proposes definitions of mobile service coverage (MSC) in three service levels, the Emergency Mobile Coverage (EMC), Basic Mobile Coverage (BMC), and Advance Mobile Coverage (AMC), based on mobile service types and the respective quality of service (QoS) requirements.

Next, two coverage metrics are proposed for identifying the mobile service coverage areas for the different service levels: data throughput and received signal power. The thresholds for these two metrics are recommended for the three levels of mobile service coverage assessment.

The proposed coverage definitions, metrics and the criteria are used to develop a unified approach to generate the coverage contours for different levels of mobile services that are available to Canadian consumers, based on the latest mobile system deployment status in Canada.

The proposed coverage definitions and metrics consider all cellular technologies, from 2G to the latest deployed 5G systems in the 3.5 GHz band.

Contents

List of Acronyms

5G NR	5G New Radio
AMR-NB	Adaptive Multi-rate – Narrow Band
AMR-WB	Adaptive Multi-rate – Wide Band
ARCEP	Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse
BEREC	Body of European Regulators for Electronic Communications
CPICH	Common Pilot Channel
ComReg	Commission for Communications Regulation
CRTC	Canadian Radio-television and Telecommunications Commission
EVS	Enhanced Voice Service
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
GSM	Global System for Mobile
GSMA	GSM Association
ISED	Innovation Science and Economic Development
LTE	Long-Term Evolution
Ofcom	Office of Communications
OTT	Over-The-Top
MNO	Mobile Network Operator
QoS	Quality of Service
ROHC	Robust Header Compression
RSRP	Reference Signal Received Power
RSCP	Received Signal Code Power
RTP	Real-Time Protocol
SINR	Signal to Interference and Noise Ratio
RxLev	Received signal level
SS RSRP	Synchronization Signal Reference Signal Received Power
STS	Spectrum and Telecommunications Sector
TDD	Time Division Duplex
TTI	Transmission Time Interval
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications Service
VoLTE	Voice over LTE
VoNR	Voice over NR

Introduction

One of the two main objectives of the "High-Speed Access for All: Canada's Connectivity Strategy" is: "*mobile wireless coverage is available where Canadians live and work, and along major road corridors.*" [1] The Canadian Radio-television and Telecommunications Commission (CRTC) collects mobile coverage contours from Mobile Network Operators (MNOs) which allows both CRTC and ISED to publish maps to show the mobile service availability within Canada. However, currently there is a lack of a unified definition of what "mobile coverage" is, and no unified agreed-upon approach to obtain these coverage contours. Therefore, different MNOs characterize the mobile coverage of their own networks based on different criteria, assumptions and coverage prediction models. This raises questions of the accuracy and consistency of mobile service coverage estimation based on these MNO-supplied contours, in particular with regard to the availability of mobile services for emergency applications.

This report first presents a literature survey on the quality requirements for different types of mobile services, the required data throughput, and the required signal power level at the receivers, based on the analyses and test results conducted by industry and other international regulatory bodies.

Based on the literature survey results, this report proposes

- Coverage definitions: definitions of mobile service coverage (MSC) for three service levels, the Emergency Mobile Coverage (EMC), Basic Mobile Coverage (BMC), and Advance Mobile Coverage (AMC), based on mobile service types and the respective quality of service (QoS) requirements; and
- Coverage metrics and criteria: two coverage metrics, data throughput and received signal power, and their respective recommended thresholds for the three service levels.

Among the two coverage metrics, it is easier to use data throughput to provide insight or likelihood on the achievable service quality, however, it is more difficult to measure in practice or to simulate[1]. The received signal power is a more commonly used metric for predicting the achievable mobile performance, since it is much easier to measure in practice and to model in simulation tools. When using this metric, it needs to first be converted into achievable data throughput for mobile service quality assessment. This conversion depends on the wireless technologies, the deployment configurations, and receiver characteristics. For coverage estimation at the cell edge, some general assumptions could be made in the analysis, for specific wireless technologies, that could provide sufficient accuracy.

The proposed coverage definitions, metrics and the criteria can be used to develop a unified approach to generate the coverage contours for different levels of mobile services that are available to Canadian consumers, based on the latest mobile system deployment status in Canada.

The proposed coverage definitions and metrics consider all RF bands applicable to all cellular technologies, from 2G to the latest deployed 5G systems including the 3.5 and 3.8 GHz bands.

[1] Methods exist to calculate maximum theoretical throughput from RSRP. However, this would be equivalent to using RSRP but more complex due to the additional steps and assumptions. Actual throughput values obtained by consumers depend on many factors, such as distribution of devices within the cell, that are not easy to estimate and vary significantly over time.

Survey of Mobile Service Scenarios and Their Throughput Requirements

This section summarizes the survey of various mobile services and their minimum/recommended data rates from various studies conducted by the providers of associated services/applications, regulatory bodies, and industry consortia.

Voice Call

Starting with 4G Long-Term Evolution (LTE), cellular networks support only packet-switched voice services such as Voice over LTE (VoLTE) calls in 4G LTE network, and Voice over New Radio (VoNR) calls in stand-alone 5G NR network. VoLTE and VoNR calls support various audio codecs such as Adaptive Muti-rate - Narrow Band (AMR-NB), Adaptive Muti-rate - Wide Band (AMR-WB), and Enhanced Voice Service (EVS).

The uplink/downlink (UL/DL) data rate requirements for VoLTE, VoNR, as well as packet-switched voice services provided by various Over-the-Top (OTT) Voice Over Internet Protocol (VoIP) applications are summarized in Table 1. The Federal Communications Commission (FCC) in the United States did not specify a minimum threshold on data throughput for VoIP calls in its guideline on broadband speed requirements ([2]).

Table 1: Data Rate Requirements for One-to-One Voice Call

Type of Voice Call	3GPP Codec Max data rate	Minimum/ recommended UL/DL data rate			
		FCC Broadband ([2])	Zoom ([6])	Skype ([7])	MS Teams ([8])
VoLTE call	- AMR-NB codec payload[2]: 4.75-12.2 kbps - AMR-WB codec payload: 6.6-23.85 kbps - EVS codec payload: 5.9-128 kbps	VoIP < 500/500 kbps	N/A	N/A	N/A
VoNR call	- AMR-NB codec payload: 4.75-12.2 kbps - AMR-WB codec payload: 6.6-23.85 kbps - EVS codec payload: 5.9-128 kbps	VoIP < 500/500 kbps	N/A	N/A	N/A
OTT VoIP application	N/A	VoIP < 500/500 kbps	60/60-80/80 kbps	30/30 - 100/100 kbps	10/10-58/58 kbps

During VoLTE/VoNR and VoIP calls, the voice codec generates an audio frame every 20 ms. For example, the AMR-WB codec used in a VoLTE/VoNR call generates a vocoded frame of 477 bits every 20 ms when operating at 23.85 kbps that then becomes the payload of the Real-time Transport Protocol (RTP) layer of the VoIP stack. For efficient usage of the cellular air-interface during VoLTE/VoNR calls, the cellular network typically performs composite header compression, or Robust Header Compression (ROHC), to reduce the size of the aggerated headers[3] produced by RTP, UDP, and IPv4/IPv6 relative to a small payload. An example of payload at different layers of a modem stack with and without ROHC produced when the vocoder operates at 23.85 kbps is summarized in Table 2.

[2] Payload is the actual service data, e.g., audio, video bit streams, not including overhead added for transmission, such as the error correction coding redundancies.

[3] Headers are part of packaging of the payload data for transfer over network connections.

Table 2: Vocoded Frame to Physical layer payload without ROHC

Vocoded Frame to Physical layer payload without ROHC		Vocoded Frame to Physical layer payload with ROHC	
Vocoded Frame	~60 bytes	Vocoded Frame	~60 bytes
↓		↓	
RTP	+ 12 bytes header	Robust Header Compression (ROHC)	+ ~5 bytes
UDP	+ 8 bytes header		
IPv6	+ 40 bytes header		
PDCP	+ 2 bytes header	PDCP	+ 2 bytes header
RLC	+ 1 byte header	RLC	+ 1 byte header
MAC	+ 2 bytes header	MAC	+ 2 bytes header
	125 bytes or 1000 bits every 20 ms		70 bytes or 560 bits every 20 ms
Physical layer		Physical layer	

Although a vocoded frame is generated every 20 ms, the transmission of this payload in a packet-switched network typically happens over one physical-layer sub-frame, which has a duration of 1 ms (also known as Transmission Time Interval or TTI in 4G LTE). From a network perspective, this bursty transmission to a single user becomes equivalent to 500 bits/1-ms (or 500 kbps) or 280 bits/1-ms (or 280 kbps), with and without robust header compression respectively, assuming a 50% voice activity factor.

At the cell edge, the uplink transmit power could be the bottleneck for VoLTE call. The cellular network typically instructs the UE to utilize a feature called "TTI bundling" which results in the UE sending the same packet in four consecutive sub-frames (i.e. over a 4-ms interval), each time with a different redundancy version (RV). Different sets of redundant data that are added for different RVs significantly improve the likelihood of successful decoding of audio packet by the network.

Video Call

The data rate requirements for video calls specified by the providers of various popular OTT applications are summarized in Table 3.

Table 3: Data Rate Requirements for Video Call

Quality/type of Video Call	Minimum/recommended UL/DL data rate				
	FCC Broadband ([2])	Zoom ([6])	Skype ([7])	MS Teams ([8])	Google Meets ([9])
1:1 Standard Definition (SD)	DL 1 Mbps	600/600 kbps	400/400 kbps – 500/500 kbps	150/150 kbps – 1.5/1.5 Mbps	1/1 Mbps
1:1 High Definition (HD)/Full-HD (FHD) call	HD: DL 1.5 Mbps	720p: 1.2/1.2 Mbps 1080p: 3.8/3 Mbps	HD: 1.2/1.2 Mbps -1.5/1.5 Mbps		3.2/2.6 Mbps

Quality/type of Video Call	Minimum/recommended UL/DL data rate				
	FCC Broadband ([2])	Zoom ([6])	Skype ([7])	MS Teams ([8])	Google Meets ([9])
Standard Definition (SD) conference	Not specified	1 Mbps/600 kbps	2 Mbps/128 kbps/2 – 5 Mbps/512 kbps (5 participants)	150/200 kbps – 2.5/4 Mbps	1.5/1 Mbps (5 participants)
High Definition (HD) conference	DL: 6 Mbps	720P: 2.6/1.8 Mbps 1080p: 3.8/3 Mbps			3.2/3.3 Mbps (5 participants)

Streaming Video

The data rate requirements for typical streaming video services specified by the providers of various popular OTT applications are summarized in Table 4.

Table 4: Data Rate Requirements for Streaming Video Services

Quality and type of Video Streaming	Minimum DL data rate [Mbps]						
	FCC Broadband ([2])	YouTube ([10])	Apple ([14])	Prime Video ([15])	Netflix ([16])	Disney+ ([17])	Hulu ([18])
SD 360p	3-4	0.7		1			1.5
SD 480p		1.1					
HD	5-8	2.5		5	≥ 3	5	3
FHD		5			≥ 5		6
4K Ultra HD (UHD)	25	20	25		≥ 15	25	16

Service-specific Requirements of Regulatory and Industry Organizations

This section summarizes the survey of mobile services and their minimum/recommended data rates, and the required minimum signal strength for different cellular networks (when available), from studies conducted by the regulatory bodies, and industry consortia.

Ofcom (Office of Communications), UK

For 2G, 3G, and 4G networks, the Office of Communications (Ofcom) in UK defines coverage based on the minimum signal strength required to, at a minimum, deliver a 98% probability of making a 90-second telephone call successfully. In the case of 4G specifically, the definition also includes a 95% chance of achieving a download speed of at least 2 Mbit/s ([12],[13]). Ofcom expects that a 4G LTE average Reference Signal Received Power (RSRP) threshold of -105 dBm is required to meet these requirements ([12], [13]). This requirement is for the cellular operators to report their coverage, who generate the coverage contours based on a confidence level of 50%. This RSRP threshold of -105 dBm

with 50% confidence level corresponds to a RSRP threshold of -115 dBm with 95% confidence level, based on the "location variability of losses" when using the ITU-R P.1812 propagation model [28].

For 5G networks, Ofcom defines coverage based on the minimum signal strength, in terms of the Synchronization Signal RSRP (SS-RSRP), required for devices to establish a reliable 5G connection ([12]). This definition supports a reporting framework for operators suitable for different variants of 5G NR in low, mid, and high frequency bands, without inferring a typical service and performance. Ofcom provides a view of outdoor 5G coverage availability across a range that provides increasing confidence of a reliable 5G connection, from high confidence (where a signal strength of -110 dBm or higher is predicted) to very high confidence (where a signal strength of -100 dBm or higher is predicted). Ofcom associates the high confidence level with at least an 80% probability of coverage being present in the predicted location, and the very high confidence level with around a 95% probability of the same. Since Ofcom expects operators to supply predictions based on a 50% confidence level of coverage being present, Ofcom has worked back from the on-the ground thresholds typically used as the limit for maintaining a 5G connection in order to establish these higher confidence levels. Ofcom particularly accounts for the overall effectiveness of operators' 5G predictions (prediction error statistics) and local level variability, as well as the differences in performance between various handsets. Ofcom assumes that the combined standard deviation across these effects amounts to ~12 dB which enables establishing signal strengths at which predictions supplied by operators, on a 50% reliability basis from a reasonable prediction model, are likely to align with the high (-110 dBm @80% availability) and very high confidence (-100dBm @95% availability) of coverage in a given location. Ofcom's compliance prediction method uses the ITU-R P.1812-4 propagation model ([27]). Details of Ofcom compliance prediction method can be found in the section titled "Overview of Ofcom's compliance model" in [13].

The signal strength thresholds used by Ofcom ([12]Table 5) when estimating coverage are summarized in Table 5.

Table 5: Ofcom Mobile Signal Strength Thresholds ([12])

Service	Network	Metric	Outdoor	Indoor and in-car
Voice	2G	RxLev[4]	-81 dBm	-71 dBm
	3G	CPICH[5] RSCP[6]	-100 dBm	-90 dBm
	4G	RSRP	-105 dBm	-95 dBm
Basic data (< 2Mbps, latency > 100 ms)	3G	CPICH RSCP	-100 dBm	-90 dBm
	4G	RSRP	-115 dBm	-105 dBm
Enhanced Data (≥ 2 Mbps DL; latency < 100 ms) and voice	4G	RSRP	-105 dBm	-95 dBm
5G high confidence		SS-RSRP	-110 dBm	
5G very high confidence		SS-RSRP	-100 dBm	

[4] RxLev - Received signal level
[5] Common Pilot Channel (C-PICH)
[6] Received Signal Code Power (RSCP)

Commission for Communications Regulation (ComReg), Ireland

ComReg commissioned a study to provide recommendations for appropriate 5G outdoor mobile coverage thresholds and Plum Consulting published a report ([31]) in 2021. According to [31], ComReg's mapping tool uses the following 2G, 3G and 4G technical thresholds for coverage categorization:

Coverage Categorization	4G (RSRP in dBm)	3G (C-PICH RSCP in dBm)	2G (RxLev in dBm)
Very good	-85 ≤ X	-75 ≤ X	-71 ≤ X
Good	-95 ≤ X <- 85	-85 ≤ X < -75	-81 ≤ X < -71
Fair	-105 ≤ X <- 95	-95 ≤ X < -85	-91 ≤ X < -81
Fringe	-115 ≤ X <- 105	-105 ≤ x < -95	-101 ≤ X < -91
No coverage	X < -115	X < -105	X < -101

The document specifies coverage categorization applicable to 4G as follows:

- Very Good: Strong signal strength with maximum data speeds.
- Good: Strong signal strength with good data speeds
- Fair: Fast and reliable data speeds maybe attained, but marginal data speeds with data dropouts are possible at weaker signal levels.
- Fringe: Disconnections likely to occur.
- No Coverage: Likely to have no coverage in this area.

Plum observes that technology differences between 4G and 5G are important factors to consider in the determination of appropriate 5G outdoor mobile coverage thresholds. Plum's recommendations for outdoor mobile coverage thresholds for 5G consider, to some extent, the different bandwidth in each band, particularly the higher bandwidth available in 3.5 GHz as well as sub-carrier spacing. Plum's recommended 5G outdoor coverage thresholds at 90% probability are shown in [31] in terms of minimum 5G SS-RSRP in dBm. Given the maturity level of 5G, Plum recommends to ComReg to indicate that 5G contours "…are intended to give an intuitive indication of 5G coverage." As for bandwidth, Plum assumes:

- 10 MHz in FDD 700, 800, and 900 MHz with 2 x 2 MIMO and sub-carrier spacing of 15 kHz
- 25 MHz in FDD 1.8 MHz, 15 MHz in FDD 2.1 GHz, 30 MHz in FDD 2.6 GHz and 80 MHz in TDD 3.5 GHz with DL:UL ratio of 8:2; all with 4 x 4 MIMO and sub-carrier spacing of 30 kHz

Table 6: 5G Coverage Thresholds recommended by Plum to ComReg (Table 6.1 in [31])

Coverage Categorization	Description	< 1 GHz	1.8 GHz & 2.1 GHz	2.3 GHz & 2.6 GHz	3.5 GHz
Very good	Strong signal strength with maximum data speeds	≥ -82.8	≥ -91.7	≥ -93.3	≥ -97.4
Good	Strong signal strength with good data speeds	≥ -92.8	≥ -101.7	≥ -103.3	≥ -107.4
Fair	Fast and reliable data speeds may be attained but marginal data speeds with data dropouts are possible at weaker signal levels.	≥ -102.8	≥ -111.7	≥ -113.3	≥ -117.4
Fringe	Marginal or poor data speeds with data disconnections likely to occur	≥ -112.8	≥ -121.7	≥ -123.3	≥ -127.4

Coverage Categorization	Description	< 1 GHz	1.8 GHz & 2.1 GHz	2.3 GHz & 2.6 GHz	3.5 GHz
No coverage	Signal strength in which no coverage is available to consumers	< -112.8	< -121.7	< -123.3	< -127.4

FCC (Federal Communications Commission), US

The FCC provides the following broadband speed guidelines for various usage scenarios ([2]):

Activity		Minimum Download Speed (Mbps)
General Usage	General Browsing and Email	1
	Streaming Online Radio	< 0.5
	VoIP Calls	< 0.5
	Student	5-25
	Telecommuting	5-25
	File Downloading	10
	Social Media	1
Watching Video	Streaming Standard Definition Video	3-5
	Streaming High Definition (HD) Video	5-8
	Streaming Ultra HD 4K Video	25
Video Conferencing	Standard Personal Video Call (e.g., Skype)	1
	HD Personal Video Call (e.g., Skype)	1.5
	HD Video Teleconferencing	6
Gaming	Game Console Connecting to the Internet	3
	Online Multiplayer	4

The FCC specifies mobile coverage maps based on the following criteria with a minimum 90% cell edge probability and minimum 50% cell loading factor ([4]):

- 3G coverage: DL/UL speeds of ≥ 200/50 kbps
- 4G LTE coverage: DL/UL speeds of ≥ 5/1 Mbps
- 5G-NR Coverage - two sets of parameters:
    - DL/UL speeds of ≥ 7/1 Mbps
    - DL/UL speeds of ≥ 35/3 Mbps

The FCC specifies the coverage requirements for different technologies but does not adopt a standardized minimum signal strength value as Ofcom does, such as RSRP. The FCC recognizes in [5] that minimum signal strength requirements depend on a large number of variables that influence the link budget analysis, including frequency band, network design, and device operating capabilities. The FCC sought comments on whether it could establish a minimum signal strength parameter value, or range of values, to accommodate such variation (in [5]); but in the end, the FCC decided in [5] not to adopt a standardized minimum signal strength parameter value. Instead, the FCC requires providers to submit

a set of maps showing RSRP in dBm as measured at the FCC-specified height of 1.5 meters above ground level ([29]) from each active cell site.

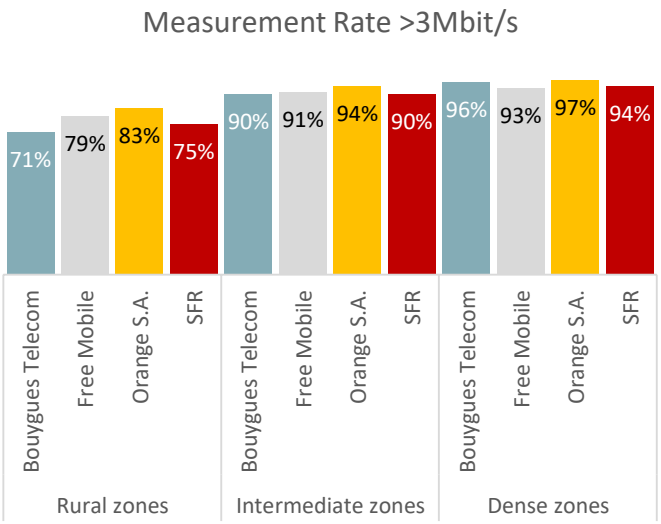
As additional information in the context of this document, the FCC performed drive testing of 4G LTE networks in 2019 and reported at the time that a minimum 4G LTE RSRP of -105 dBm was required to achieve a DL data rate of ≥ 5 Mbps 80% of the time ([11]).

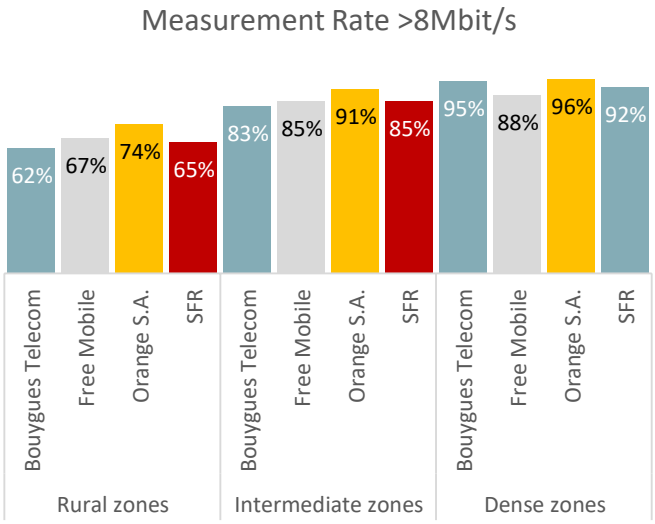
ARCEP (Autorité de Régulation des Communications Électroniques, des Postes et de la Distribution de la Presse), France

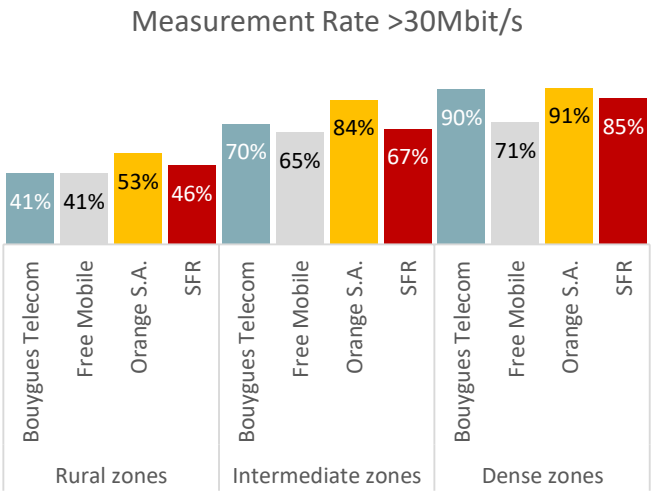
The ARCEP, the France's Electronic Communications, Postal and Print media distribution Regulatory Authority, defines the following criteria for evaluating performance of following usage scenarios as follows ([20]):

- **Voice**: the success rate for maintaining a two-minute call without audible disturbance
- **Text**: the ability to receive a text in under 10 seconds
- **Mobile Internet Usage Scenarios**:
    - For the least demanding mobile internet uses (such as Web browsing): data rate ≥ 3 Mbps
    - For the most common mobile internet uses (e.g., watching videos): data rate ≥ 8 Mbps
    - For the most demanding uses (e.g., use of collaborative tools in the workplace): ≥ 30 Mbps

ARCEP publishes the results of its annual audit evaluating the quality of the services provided by the mobile operators. An example is shown Figure 1 for mobile internet performance which is based on more than a million measurements taken of 2G, 3G, 4G and 5G networks in Metropolitan France, between mid-May and mid-August 2023 ([20]).







Figures 1: Mobile Internet Performance by Operators in Rural, Medium and High Density Areas ([20])

Long description

Zone	Company	>3Mbit/s	>8Mbit/s	>30Mbit/s
Rural zones	Bouygues Telecom	71%	62%	41%
	Free Mobile	79%	67%	41%
	Orange S.A.	83%	74%	53%
	SFR (Société Française du Radiotéléphone)	75%	65%	46%
Intermediate zones	Bouygues Telecom	90%	83%	70%
	Free Mobile	91%	85%	65%
	Orange S.A.	94%	91%	84%
	SFR	90%	85%	67%

Zone	Company	>3Mbit/s	>8Mbit/s	>30Mbit/s
Dense zones	Bouygues Telecom	96%	95%	90%
	Free Mobile	93%	88%	71%
	Orange S.A.	97%	96%	91%
	SFR	94%	92%	85%

Similar to the FCC, ARCEP has not adopted any requirements for minimum signal level thresholds associated with these services.

Body of European Regulators for Electronic Communications (BEREC)

The Body of European Regulators for Electronic Communications (BEREC) published a document ([30]) in 2018 that provides a useful summary of existing coverage thresholds (to qualify if there is outdoor coverage or not) adopted in different European countries, which is shown in Table 7

Table 7: Thresholds used in European Countries (Appendix 2 in [30])

Country	Regulatory Organization	2G RxLev Threshold	3G UMTS RSCP Threshold	4G LTE RSRP Threshold
Belgium	BIPT	Not specified	Satisfying -105 dBm, Good -95 dBm , Very good -85 dBm	Satisfying -115 dBm , Good -105 dBm, Very good -95 dBm
Bulgaria	CRC	≥ -100 dBm	≥ -105 dBm	≥ -110 dBm
Croatia	HAKOM	- 95 dBm	> -114 dBm	> -115 dBm
Czech Republic	CTU	900 MHz: > -93 dBm, 1800 MHz: > -91 dBm	2100 MHz: > -86 dBm	900 MHz: > -109 dBm 1800 MHz: > -107 dBm 2100 MHz: > -106 dBm 2600 MHz: > -105 dBm
Finland	FICORA	≥ -90 dBm	≥ -100 dBm	≥ -110 dBm
Greece	EETT	> -110 dBm	> -115 dBm	> -125 dBm
Hungary	NMHH	>-93 dBm	> -96 dBm	> -110 dBm
Iceland	PTA	-75 dBm in town, -95 dBm in rural	-85 dBm in town, -100 dBm in rural	-85 dBm in town, -100 dBm in rural
Lithuania	RRT	>-95 dBm	>-105 dBm	>-115 dBm
Macedonia	AEC	>-95 dBm	>-105 dBm	>-110 dBm
Norway	NKOM	>-90 dBm	>-100 dBm	>-110 dBm
Portugal	ANACOM	>-105 dBm	>-115 dBm	>-125 dBm
Romania	ANCOM	>-92 dBm	>-107 dBm	>-112 dBm
Serbia	RATEL	>-95 dBm	>-105 dBm	>-110 dBm
Slovenia	AKOS	>-93 dBm	>-96 dBm	>-108 dBm
Sweden	PTS	>-99 dBm	>-104 dBm	>-111 dBm

Country	Regulatory Organization	2G RxLev Threshold	3G UMTS RSCP Threshold	4G LTE RSRP Threshold
Belgium	BIPT	Not specified	Satisfying -105 dBm, Good -95 dBm , Very good -85 dBm	Satisfying -115 dBm , Good -105 dBm, Very good -95 dBm
Bulgaria	CRC	≥ -100 dBm	≥ -105 dBm	≥ -110 dBm
Croatia	HAKOM	- 95 dBm	> -114 dBm	> -115 dBm
Czech Republic	CTU	900 MHz: > -93 dBm, 1800 MHz: > -91 dBm	2100 MHz: > -86 dBm	900 MHz: > -109 dBm 1800 MHz: > -107 dBm 2100 MHz: > -106 dBm 2600 MHz: > -105 dBm
Finland	FICORA	≥ -90 dBm	≥ -100 dBm	≥ -110 dBm
Greece	EETT	> -110 dBm	> -115 dBm	> -125 dBm
Hungary	NMHH	>-93 dBm	> -96 dBm	> -110 dBm
Iceland	PTA	-75 dBm in town, -95 dBm in rural	-85 dBm in town, -100 dBm in rural	-85 dBm in town, -100 dBm in rural
Lithuania	RRT	>-95 dBm	>-105 dBm	>-115 dBm
Macedonia	AEC	>-95 dBm	>-105 dBm	>-110 dBm
Norway	NKOM	>-90 dBm	>-100 dBm	>-110 dBm
Portugal	ANACOM	>-105 dBm	>-115 dBm	>-125 dBm
Turkey	ICTA	>-104 dBm	>-110 dBm	Not specified
UK	Ofcom	>-81 dBm	>-100 dBm	>-105 dBm

GSMA (Global System for Mobile Communications Association)

VoLTE Call

The Mean Opinion Score (MOS) is a widely used metric for assessing quality of a voice call. Standardized by the International Telecommunications Union (ITU-T), MOS refers to a numerical measure of the human-judged overall quality of voice session; it is judged on a scale from 1 (bad) to 5 (excellent) of the perceived quality of a voice call. ITU-T provides the guidelines for quality measurement of VoLTE calls in [28].

GSMA recommends that the bottom 10% MOS value (10^{th} percentile MOS) be used as a metric to assess the quality of network deployment ([19]). The MOS score during a voice call is affected by the codec, transmission latency, jitter, and packet loss. VoLTE supports various voice codecs such as EVS, AMR-WB, and AMR-NB. The AMR-WB codec supports a data rate of 6.6-23.85 kbps whereas AMR-NB supports a data rate of 4.75-12.2 kbps. Based on the field test data of 23.85 kbps AMR-WB VoLTE calls on a 4G network, GSMA recommends the following minimum signal levels in a 4G network to achieve a target of 10^{th} percentile MOS score ([19]):

10th Percentile MOS Score	LTE RSRP (dBm)	SINR (dB)
2.5	-112	-4
3	-108	-3

10th Percentile MOS Score	LTE RSRP (dBm)	SINR (dB)
3.5	-103	2

* MOS Score: 1 – bad, 2 – Poor, 3 – Fair, 4 – Good, 5 – Excellent

Recommendations on Mobile Coverage Definition and Metrics

Mobile Coverage Definitions

To provide a detailed characterization of mobile service coverage, it is proposed to define the geographical coverage areas for three different levels of mobile services for outdoor reception conditions:

Emergency Service (Voice Call, SMS text, Public Warning System)

- For Emergency Service, the coverage is defined as the area where:
  - Emergency voice: the system is capable of delivering a 95% probability of supporting a 90 second emergency voice call without interruption and with adequate audio quality (recommended MOS score: ≥ 2.5 for 90% of calls)
  - Public Warning System (PWS): the system is capable of delivering PWS services such as a Cell Broadcasting Service (CBS) or Commercial Mobile Alert System (CMAS) with a 100% success rate.

Basic Service (emergency service plus voice and video calls, and medium data-rate service)

- For Basic Service, the coverage is defined as the area where:
  - Voice: the system is capable of delivering a 95% probability of supporting a 90 second voice call or video call without any interruption with high voice quality (recommended MOS score: ≥ 3 for 90% of calls); and
  - Data: the system is capable of delivering a 95% probability of supporting a data service that requires a downlink data rate of at least 3 Mbps and an uplink data rate of at least 1 Mbps.

Advanced Service (Basic service plus higher data service)

- For Advanced Service, the coverage is defined as the area where:
  - Voice: the system is capable of delivering a 95% probability of supporting a 90 second voice call or video call without any interruption with high voice quality (recommended MOS score: ≥ 3 for 90% of calls); and
  - Data: the system is capable of delivering a 95% probability of supporting a data service that requires a consistent downlink data rate of at least 10 Mbps and an uplink data rate of at least 2 Mbps.

Metrics to Determine Mobile Coverage

The coverage areas could be determined by two set of metrics: the throughput and the received downlink power level.

Metric-1: Service data throughput with latency requirements

This metric could be given to the operators to comply and provide a response; but it would be difficult for an external organization to generate these contours in order to validate them[1]. Theoretically, the maximum available throughput for a given RSRP level can be calculated; in which case the contours derived from RSRP and throughput would be equivalent. However, the actual throughput achieved at any particular time and place will depend on many factors –

such as the number of users currently connected to the cell and their distribution in space from the transmitter – making it a more difficult metric to validate.

- Emergency Service: downlink data rate ≥ 250 kbps, uplink data rate ≥ 250 kbps; latency: ≤ 150 ms for voice
- Basic Service: downlink data rate ≥ 3 Mbps, uplink data rate ≥ 1 Mbps; latency: ≤ 100 ms for voice and < 150 ms for data
- Advanced Service: downlink data rate ≥ 10 Mbps, uplink data rate ≥ 2 Mbps, latency: ≤ 100 ms

Metric-2: Downlink received signal power level

This metric provides a simpler way to predict coverage and is the recommended metric. It is assumed that the downlink and uplink are balanced such that any potential uplink power imbalance issue is addressed by the network via mechanisms such as TTI bundling. As such, the metric being considered is the received signal power level for the downlink. This strategy is similar to the one used by Ofcom and is implicitly tied with an assumption of what services are supported. However, individual services may need to be separately verified for a given signal power level threshold.

The indicators of downlink signal power depend on the underlying radio access technology and are measured as follows:

- 2G GSM: the received signal strength (RxLev) of the GSM cell
- 3G UMTS: the Received Signal Code Power (RSCP) of the common Pilot Channel (CPICH)
- 4G: the Reference Signal Received Power (RSRP)
- 5G: the Synchronization Signal Reference Signal Received Power (SS-RSRP)

The following signal level thresholds are recommended for various levels of services:

- Emergency Service:
    - 2G: GSM RxLev: minimum -90 dBm
    - 3G: C-PICH RSCP: minimum -100 dBm
    - 4G/5G: 4G RSRP or 5G SS RSRP: minimum -110 dBm for outdoor
- Basic Service:
    - 3G: C-PICH RSCP minimum -95 dBm
    - 4G/5G: RSRP or 5G SS RSRP: minimum -105 dBm for outdoor
- Advanced Service: 4G RSRP or 5G SS RSRP: minimum -100 dBm for outdoor

The reasoning and rationale behind these levels are given in below.

Metric-2 for Emergency Service

- Emergency voice call: To ensure that an emergency call can reliably be placed, a minimum threshold RSRP of >= -110 dBm in 4G is required according to available information from drive test results ([19], [21], [22]). At this signal strength, 90% of calls are expected to have a MOS score of ≥ 2.5 ([19]) assuming a lower data rate AMR codec is used. It is further assumed that the network utilizes the uplink Transmission Time Interval (TTI) bundling feature if cell edge coverage becomes uplink limited. The network is expected to use robust header compression (ROHC) for emergency VoLTE/VoNR calls.
- For the purpose of network selection by the UE, 3GPP defines a 2G, 3G, and 4G/5G cell with “high quality signal” level as cell with a signal level ≥ -85 dBm ([23]), ≥ -95 dBm ([24]), and ≥ -110 dBm respectively. The UE uses this parameter to prioritize cells that provide subscribed service, which may also include cells below this signal level.
- The median and average values of the minimum 4G RSRP thresholds for coverage used by various European operators as listed in [30] are -110 dBm and -112 dBm respectively.

- The median and average values of the minimum 3G RSCP thresholds used by various European operators as listed in [30] are -105 dBm and -104 dBm respectively. The 3G threshold for voice set by Ofcom is -100 dBm.
- The median and average values of the minimum 2G RxLev thresholds used by various European operators as listed in [30] are -95 dBm and -96 dBm respectively.

Metric-2 for Basic Service

- Non-emergency Voice and Video calls: 90% of VoLTE calls are expected to have a MOS score of ≥ 3 ([19]); 5 dB is added relative to emergency voice call to accommodate an increase in MOS score as well as higher data-rate audio codecs, such as the EVS codec, required for higher audio quality (HD/HD+) particular for 5G VoNR calls. It is further assumed that the network utilizes the uplink Transmission Time Interval (TTI) bundling feature if cell edge coverage becomes uplink limited. The network is expected to use robust header compression (ROHC) for emergency VoLTE/VoNR calls.
- Ofcom's threshold for voice calls and to achieve a downlink data rate of at least 2 Mbps in 4G is -105 dBm ([12]).
- The FCC indicated in [11] that a minimum RSRP of -105 dBm was required in 4G LTE to achieve a DL data rate of ≥ 5 Mbps in 4G LTE network 80% of the time ([11]).

Metric-2 for Advanced Service

- Advanced service requires higher data rates and more stringent latency requirements. Hence the threshold is increased to -100 dBm.
- The threshold is the same as Ofcom's 5G threshold with very high confidence interval ([12]).

The identified metrics with their respective thresholds for the different levels of mobile services are summarized in Table 8. For each service level, some example services are also listed with their UL/DL data rate requirements.

Table 8 – Metrics and thresholds for coverage assessment for different levels of mobile services

<table>
<tr><th rowspan="3">Service Level</th><th rowspan="3">Examples of Service</th><th rowspan="3">Minimum UL/DL rate requirements for example services</th><th rowspan="3">Metric-1: DL/UL Throughput, Latency</th><th colspan="4">Metric-2: Downlink power level</th></tr>
<tr><th colspan="2">Minimum 4G RSRP (dBm)</th><th colspan="2">Minimum 5G SS RSRP (dBm)</th></tr>
<tr><th>Outdoor</th><th>Indoor</th><th>Outdoor</th><th>Indoor</th></tr>
<tr><td rowspan="3">Emergency</td><td>Emergency Voice (VoLTE/VoNR) with 90% MOS score ≥ 2.5</td><td>DL/UL 250 kbps</td><td rowspan="3">DL/UL:
> 250/250 kbps

latency requirement < 150 ms</td><td rowspan="3">-110</td><td rowspan="3">-100</td><td rowspan="3">-110</td><td rowspan="3">-100</td></tr>
<tr><td>Point to point Text messaging (SMS)</td><td>SMS: max 170 bytes per message</td></tr>
<tr><td>Public Warning System broadcast text messages CBS or CMAS</td><td>93 bytes per message and up to 15 concatenated messages (total of 1395 bytes)</td></tr>
<tr><td rowspan="2">Basic</td><td>Basic Email</td><td>DL: 1 Mbps</td><td rowspan="2">DL/UL:
> 3/1 Mbps</td><td rowspan="2">-105</td><td rowspan="2">-95</td><td rowspan="2">-105</td><td rowspan="2">-95</td></tr>
<tr><td>Social Media Messaging with occasional Images</td><td>DL: 1 Mbps</td></tr>
</table>

Service Level	Examples of Service	Minimum UL/DL rate requirements for example services	Metric-1: DL/UL Throughput, Latency	Metric-2: Downlink power level			
				Minimum 4G RSRP (dBm)		Minimum 5G SS RSRP (dBm)	
				Outdoor	Indoor	Outdoor	Indoor
	Voice with 90% MOS score ≥ 3 (VoLTE/VoNR, OTT VoIP)	500/500 kbps	Latency < 150 ms				
	1:1 SD Video Call	1/1 Mbps					
	1:1 HD Video call	1.5/1.5 Mbps					
	Basic Web browsing	DL: 3 Mbps DL					
Advanced	HD Video conference call	4/3 Mbps	DL/UL: > 10/2 Mbps Latency < 100 ms	-100		-100	
	Social Media with occasional Images	DL: 5 Mbps					
	HD/FHD Video Streaming	DL: 6 Mbps					
	4K UHD Streaming	DL: 25 Mbps					
	Telecommuting	DL: 25 Mbps					

5G considerations

It is assumed that legacy low FDD bands, which have much lower bandwidth compared to the new mid and high TDD bands, are expected to be used for emergency voice and basic services in 4G and 5G networks. Hence, the expectation is that there will not be much difference between 4G and 5G thresholds at the cell edge as long as low FDD bands are used. For advanced services, which require higher throughputs, or to increase capacity, 5G networks can utilize mid bands that have much higher bandwidths compared to legacy low bands. Therefore, 5G thresholds may need to be revisited in the future when adequate field data is available in mid bands.

The high bands, such as mmWave bands, which have very large bandwidth are not considered in this technical report. These bands have yet to be licensed or deployed in Canada.

Conclusions

Based on an extensive review of a wide range of mobile broadband services and their quality characterizations both from the telecommunications industry and international regulators, this report proposes a definition of mobile service coverage comprised of three levels of mobile services:

- **Emergency Service**: a 95% probability of making a 90 second emergency voice call without interruption and with adequate audio quality (recommended MOS score: ≥ 2.5 for 90% of calls) and a 100% probability of receiving Public Warning System messages; the data rate requirement for this service is at least 250 kbps for both the uplink and the downlink
- **Basic Service**: a 95% probability of making a 90 second voice call or video call without any interruption with high voice quality (recommended MOS score: ≥ 3 for 90% of calls); and a 95% probability of a data service with a downlink data rate of at least 3 Mbps and an uplink data rate of at least 1 Mbps

- **Advanced Service**: a 95% probability of making a 90 second voice call or video call without any interruption with high voice quality (recommended MOS score: ≥ 3 for 90% of calls); and a 95% probability of data service with a consistent downlink data rate of at least 10 Mbps and an uplink data rate of at least 2 Mbps.

Two metrics are proposed to identify mobile coverage areas corresponding to these metrics: downlink data throughput and the received signal power levels. CRC recommends using received signal power level as it is relatively easy to calculate and measure in the field. Radio access technology dependent radio signal strength levels are the most commonly used criteria to define mobile coverage at this time. The outcome of the survey by BEREC ([30]) shows that 22 out of 33 national regulatory organizations in Europe define received signal power thresholds for the classification of different levels of mobile coverage.

The proposed definition of mobile service coverage, metrics, and the associated recommended thresholds will be used to develop a unified approach to generate the coverage contours for different levels of mobile services that are available to Canadian consumers, based on the latest mobile system deployment status in Canada.

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Terminologies

Adaptive Multi-Rate Narrow band (**AMR-NB**): A speech codec that encodes narrowband (200–3400 Hz) signals at variable bit rates ranging from 4.75 to 12.2 kbit/s (4.75, 5.15, 5.90, 6.70, 7.40, 7.95, 10.2, and 12.2 kbps). AMR was adopted as the standard speech codec by 3GPP in October 1999 and is widely used in GSN, UMTS, and LTE networks.

Adaptive Multi-Rate Wideband (AMR-WB): A speech codec that utilizes the ACELP® (Algebraic Code Excited Linear Prediction) technology, which is also employed in the AMR narrowband. The AMR-WB speech codec consists of nine bit rates of 6.6, 8.85, 12.65, 14.25, 15.85 18.25, 19.85, 23.05, and 23.85 kbps. It is the first codec to be standardized for both wireless (3GPP) and wireline (ITU-T Recommendation G.722.2) applications. It provides improved speech quality due to a wider speech bandwidth of 50–7000 Hz compared to narrowband speech coders.

Enhanced Voice Services (**EVS**): EVS is a super wideband (20-20000 Hz) codec provides high robustness against delay jitter and packet losses due to its channel aware coding and improved packet loss concealment. EVS was standardized by 3GPP as a successor of AMR-WB. EVS codec supports operating points from narrow band (5.9-24.4 kbps) to full band (16.4-128 kbps).

Mean Opinion Score: Usually referred to as **MOS** Score, has been the most commonly used metric to measure the overall voice call quality for decades. Standardized by the International Telecommunications Union (ITU-T), it is a subjective measurement on a scale usually from 1 (bad) to 5 (excellent). MOS testing for VoIP phone networks is defined in the ITU-T PESQ P.862 standard.

4G Reference Signal Received Power (4G RSRP): The linear average power of the 4G resource elements that carry cell-specific reference signals. RSRP measurements are used by mobile for cell selection/re-selection, power control, beam management, mobility procedure such as handover.

5G Synchronization Signal-Reference Signal Received Power (5G SS-RSRP): average power measured over a single resource element of Secondary Synchronization Signal (SSS). SS-RSRP measurements are used for cell selection/re-selection, power control, beam management, mobility procedure such as handover. Mobile uses the minimum RSRP and the RSRQ thresholds broadcast by the 5G network for initial 5G cell selection and subsequent re-selection.