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Requirements and Evaluation on mmWave Radio Interface Technology (RIT) for IMT-2020 (5G)

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Abstract

International Telecommunication Union (ITU) embarked on a programme to develop IMT-2020 as a new international standard name for fifth generation mobile systems and has set the minimum performance requirements and evaluation methodologies of IMT-2020. IMT-2020 systems will be the mobile systems that include new radio interface which support the new capabilities of systems beyond IMT-Advanced. In particular, the data rate of IMT-2020 is expected to be 10 times to 20 times larger compared to IMT-Advanced for enhanced Mobile Broadband. In order to achieve this requirement, mmWave band and micro-cell deployment are essential. In this paper, we proposed candidate technology for IMT-2020 and consider evaluation results which are theoretically expected data rate and system level simulation for spectral efficiency. When the micro-cells in indoor hotspot are deployed, the expected data rate user spectral efficiency with mmWave radio interface technology through 12 TRxP and 36 TRxP has met with IMT-2020 requirement. The evaluation of dense urban eMBB scenario should be needed for proofing outdoor performance with mmWave in the next stage towards 5G reality.

Keywords: ITU, IMT-2020, 5G, mmWave, Radio Interface Technology, eMBB

INTRODUCTION

IMT could play to better serve the needs of the networked society. In early 2012, International Telecommunication Union (ITU) embarked on a programme to develop "IMT for 2020 and beyond", setting the stage for 5G research activities. In September 2015, ITU has finalized its "Vision" of the 5G mobile broadband connected society. IMT Vision – "Framework and overall objectives of the future development of IMT for 2020 and beyond" (Recommendation ITU-R M.2083, 2015) provides 3 usage scenarios and the key capabilities of IMT-2020, compared with those of IMT Advanced. The minimum requirements and usage scenarios for IMT-2020 radio interface technology are summarized in Figure 1.

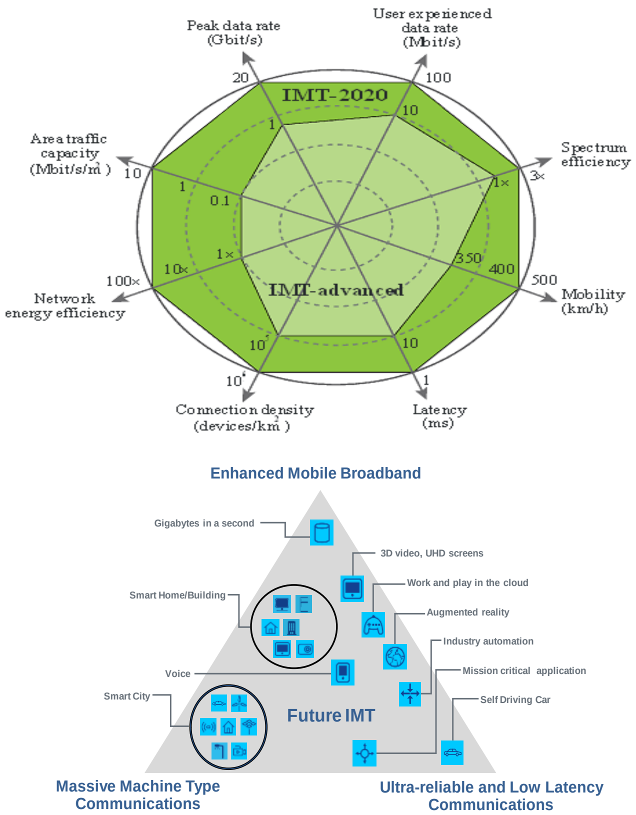


Figure 1: Key capabilities from IMT-Advanced to IMT-2020 and 3 usage scenarios [1]

The capabilities of IMT-2020 are identified, which aim to make IMT-2020 more flexible, reliable and secure than previous IMT when providing diverse services in the intended enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine type communications (mMTC). Keys are 20 Gbps of Peak data rate, 3 times of spectral efficiency, up to 1 GHz of Bandwidth, very low latency of 1 ms, etc.

In order to increase the data rate, it is necessary to use a wide frequency band or to use the spectrum efficiently. Since the channel bandwidth that can be used for wireless communication is limited, IMT-Advanced mobile communication improves spectral efficiency. The technologies such as Orthogonal Frequency-Division

Multiplexing (OFDM) and Multiple-Input and Multiple-Output (MIMO) have contributed greatly to improve spectral efficiency. Therefore, IMT-2020 tries to meet the data rate requirement by using the mmWave and small cell deployment [2].

To achieve the IMT-2020 data rate requirements, the use of mmWave band and micro-cell deployment is essential. In this paper, we proposed mmWave radio interface technology as a candidate technology for IMT-2020 by 2020 and consider evaluation results which are theoretically expected data rate and system level simulation in small cell deployment to continue further improvement and fulfilment towards 5G reality.

The remainder of this paper is organized as follows: In Section 2, technical performance requirements and evaluation methodology for IMT-2020, focusing on small cell deployment, based on ITU-R Report M.2410 and M.2412 presented. In Section 3, candidate technology for IMT-2020 based on analysis of 3GPP technology and mmWave requirements is proposed. In Section 4, evaluation results are presented for ensuring candidate technology is met with requirements on mmWave eMBB. Finally, Section 5 concludes the paper.

Technical Performance Requirements and Evaluation Methodology

ITU defined test environment reflects a combination of geographic environment and usage scenario. There are five selected test environments for IMT-2020 as follows [3]:

- Indoor Hotspot-eMBB: An indoor isolated environment at offices and/or in shopping malls based on stationary and pedestrian users with very high user density.
- Dense Urban-eMBB: An urban environment with high user density and traffic loads focusing on pedestrian and vehicular users.
- Rural-eMBB: A rural environment with larger and continuous wide area coverage, supporting pedestrian, vehicular and high speed vehicular users.
- Urban Macro–mMTC: An urban macro environment targeting continuous coverage focusing on a high number of connected machine type devices.
- Urban Macro–URLLC: An urban macro environment targeting ultra-reliable and low latency communications.

The mapping of the five test environments and the three usage scenarios is given in Table 1.

Table 1: Mapping of test environments and usage scenarios

eMBB			mMTC	URLLC
Indoor Hotspot – eMBB	Dense Urban – eMBB	Rural – eMBB	Urban Macro – mMTC	Urban Macro – URLLC

Especially, mmWave will be used as backhaul network for moving hotspots, such as buses, to showcase the world first 5G entertainment system. After 2020, mmWave based Vehicle-to-Vehicle (V2V)/ Vehicle-to-everything) V2X services will be deployed, in order to realize automated driving in complex urban environments [4]. Indoor hotspot-eMBB and Dense Urban-eMBB will be main deployment scenarios.

IMT-2020 can be considered from multiple perspectives, including the users, manufacturers, application developers, network operators, and service and content providers. Therefore, it is recognized that technologies for IMT-2020 can be applied in a variety of deployment scenarios and can support a range of environments, service capabilities, and technology options. The key minimum technical performance requirements defined in ITU-R Report M.2410 are for the purpose of consistent definition, specification, and evaluation of the candidate IMT-2020 radio interface technologies (RITs)/Set of radio interface technologies (SRIT) in conjunction with the development of detailed specifications of IMT-2020. Key performance indicators (KPIs) are greater than 10Gbit/s peak data rate, 100Mbit/s user-experienced data rate, 3x spectrum efficiency, greater than 100 Mbps cell edge rates, 10Mbit/s/km2 area traffic capacity, 100x network energy efficiency, 1ms over-the-air latency, support for 500km/h mobility, and 106km2 connection density [5]. mmWave communications [6], [7], [8], [9], [10], [11] which using mmWave bands from 30 GHz to 300 GHz is widely considered and identified for the most important technologies to achieve 10Gbit/s peak data rate for eMBB scenario and following Table 2 shows key performance requirements for them.

Table 2: Technical Performance Requirements and Evaluation Method for eMBB

Key Requirements for eMBB	Minimum Value	Calculation Methodology
Peak Data Rate [Gbps]	Downlink(DL) 20, Uplink(UP) 10	Analytical
Peak Spectral Efficiency [bit/s/Hz]	DL 30, UL 15	Analytical
5th Percentile User Spectral Efficiency [bit/s/Hz]	Indoor Hotspot-eMBB (DL 0.3, UL 0.21)	Simulation
Average Spectral Efficiency [bit/s/Hz]	Indoor Hotspot-eMBB (DL 9, UL 6.75)	Analytical

Network layouts [3] for Indoor Hotspot-eMBB in Figure 2 as main usecase for mmWave are considered in this paper.

The configuration parameters shall be applied in analytical and simulation assessments of candidate RIT for IMT-2020.

As defined in Report ITU-R M.2412, configuration B for carrier frequency 30 GHz [3] as shown in Table 3 considered in this paper for evaluation.

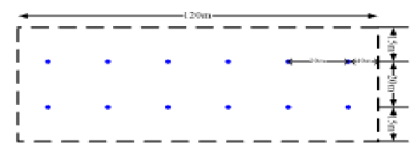
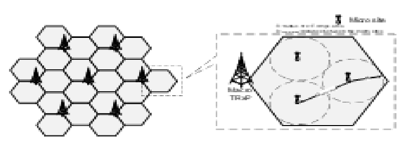
Indoor Hotspot-eMBB		• One floor with 3m height • 120m x 50m, 12 BSs/sites (spacing 20m) • LOS
Dense urban-eMBB		• Two layers (macro and micro) • Macro-layer - regular hexagonal • Micro-layer - 3 Micro per Macro

Figure 2: Network Layouts for Evaluation

Table 3: Evaluation configuration for Indoor Hotspot-eMBB test environment

Parameters	Indoor Hotspot-eMBB		
	Spectral Efficiency, Mobility, and Area Traffic Capacity Evaluations		
	Configuration A	Configuration B	Configuration C
Baseline evaluation configuration parameters			
Carrier frequency for evaluation	4 GHz	30 GHz	70 GHz
BS antenna height	3 m	3 m	3 m
Total transmit power per TRxP	24 dBm for 20 MHz bandwidth 21 dBm for 10 MHz bandwidth	23 dBm for 80 MHz bandwidth 20 dBm for 40 MHz bandwidth e.i.r.p. should not exceed 58 dBm	21 dBm for 80 MHz bandwidth 18 dBm for 40 MHz bandwidth e.i.r.p. should not exceed 58 dBm
UE power class	23 dBm	23 dBm e.i.r.p. should not exceed 43 dBm	21 dBm e.i.r.p. should not exceed 43 dBm
Additional parameters for system-level simulation			
Inter-site distance	20 m	20 m	20 m
Number of antenna elements per TRxP	Up to 256 Tx/Rx	Up to 256 Tx/Rx	Up to 1024 Tx/Rx
Number of UE antenna elements	Up to 8 Tx/Rx	Up to 32 Tx/Rx	Up to 64 Tx/Rx
Device deployment	100% indoor Randomly and uniformly distributed over the area	100% indoor Randomly and uniformly distributed over the area	100% indoor Randomly and uniformly distributed over the area
UE mobility model	Fixed and identical speed |v| of all UEs, randomly and uniformly distributed direction	Fixed and identical speed |v| of all UEs, randomly and uniformly distributed direction	Fixed and identical speed |v| of all UEs, randomly and uniformly distributed direction
UE speeds of interest	100% indoor, 3 km/h	100% indoor, 3 km/h	100% indoor, 3 km/h
Inter-site interference modeling	Explicitly modelled	Explicitly modelled	Explicitly modelled
BS noise figure	5 dB	7 dB	7 dB
UE noise figure	7 dB	10 dB	10 dB
BS antenna element gain	5 dBi	5 dBi	5 dBi

Channel model for system level simulation can be selected either Model A (3GPP TR38.901 in case above 6 GHz) and Model B (3GPP TR38.901 in case from 0.5 GHz to 100 GHz) in Report ITU-R M.2412. To ensure that IMT-2020 technologies are able to fulfil the objectives of IMT-2020 and to set a specific level of performance that each proposed technology need to achieve in order to be accepted within ITU-R for IMT-2020 and evaluation process is essential.

mmWave Radio Interface Technology features

As previous IMT-Advanced vision, IMT-2020 (5G) vision will cause a fundamental change in the mobile networks, starting with physical layer (PHY). The core PHY technologies, that will set 5G New Radio (NR) are mmWave and massive MIMO. This Radio Interface Technology (RIT) will be capable to support IMT identified bands including mmWave bands for supporting dual connectivity of LTE and NR. The maximum channel bandwidth is 100 MHz for low frequency and 400 MHz for high frequency. By aggregating up to 16 component carriers, transmission bandwidth up to at least 1.6 GHz and 6.4 GHz are respectively supported for low and high frequency to provide high peak data rates. The RIT supports Discontinuous Reception (DRX) mode operation. In DRX mode operation, the physical layer in the UE shall assess the radio link quality. Multiple access based on a combination of OFDMA, TDMA, CDMA, SDMA. π/2-BPSK (uplink only when transform precoding enabled), QPSK, 16QAM, 64QAM, 256QAM. The RIT supports two test environments under eMBB and one test environment under URLLC usage scenario which are Indoor Hotspot-eMBB, Dense Urban-eMBB, and Urban Macro-URLLC. The proposed technology targets to support a wide range of services across the diverse usage scenarios including eMBB, URLLC, envisaged in Recommendation ITU-R M.2083. Main features of 5G mmWave RIT presents in Table 4.

Table 4: Features of candidate mmWave RIT for IMT-2020

Features	Characteristics and Description
Spectrum	Flexible spectrum use is supported by using one or multiple component carriers. High frequency bands 26.5 - 29.5 GHz and 24.25 - 27.5 GHz supported
Bandwidths	The maximum channel bandwidth is 400 MHz for frequencies 24.25 GHz ~ 52.6 GHz
Multiple access schemes	Multiple access based on a combination of - OFDMA: Transmission to/from different UEs using mutually orthogonal frequency assignments. Multiple OFDM numerologies are supported.. Granularity in frequency assignment: One resource block consisting of twelve subcarriers over one OFDM symbol. DFT-spread OFDM is also used in uplink. - TDMA: Transmission to/from different UEs with separation in time. Granularity: 14-symbol duration for slot-based operation, less than slot duration with 2, 4, 7 symbol-duration granularities for non-slot based operation, regardless of OFDM numerology. - CDMA: Inter-cell interference suppressed by processing gain of channel coding and/or spreading allowing for a frequency reuse of one. - SDMA: Possibility to transmit to/from multiple users using the same time/frequency resource (SDMA or multi-user MIMO) as part of the advanced-antenna capabilities.
Modulation Scheme	Data and higher-layer control: π/2-BPSK (uplink only when transform precoding enabled), QPSK, 16QAM, 64QAM, 256QAM L1/L2 control: π/2-BPSK, BPSK and QPSK for uplink control channel (PUCCH), QPSK for downlink control channel (PDCCH) Symbol rate: 168 and 144 symbols per resource block per slot for normal and extended CP, respectively. Symbol rate per resource block per slot depends on sub-carrier spacing.
Frame topology	Subcarrier spacings of 15, 30, 60, 120, and 240 kHz are supported. For synchronization signals, 15 and 30 kHz are supported for frequency range 1 (450 MHz ~ 6 GHz), and 120 and 240 kHz are supported for frequency range 2 (24.25 GHz ~ 52.6 GHz). For control and data channels, 15, 30, and 60 kHz are supported for frequency range 1, and 120 kHz are supported for higher frequency range. One radio frame of length 10 ms consists of 10 subframes, each of length 1 ms. Each subframe consists of 1, 2, 4, 8, and 16 slots for subcarrier spacing of 15, 30, 60, 120, and 240 kHz, respectively. Each slot consists of 14 OFDM symbols in case of normal cyclic prefix and 12 OFDM symbols in case of extended cyclic prefix. In TDD, per each slot, up to 2 DL-to-UL switching points are allowed. One or more OFDM symbols serve as a guard time between DL and UL.

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DISCUSSION

As Report ITU-R M.2410 [5], a straight forward calculation will be enough to evaluate peak data rate, peak spectral efficiency and area traffic capacity.

The peak data rate is the maximum achievable data rate under ideal conditions (in bit/s). In case bandwidth is aggregated across multiple bands, the peak data rate will be summed over the bands. Therefore, if bandwidth is aggregated across Q bands then the total peak data rate is

$$R = \sum_{i=1}^{Q} W_i \times SEp_i \tag{1}$$

where Wi and SEpi (i = 1,…Q) are the component bandwidths and spectral efficiencies respectively.

The peak spectral efficiency is the maximum data rate under ideal conditions normalised by channel bandwidth (in bit/s/Hz), where the maximum data rate is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

The area traffic capacity is derived based on the achievable average spectral efficiency, TRxP density and bandwidth. Let W denote the channel bandwidth and ρ the TRxP density (TRxP/m2). The area traffic capacity Carea is related to average spectral efficiency SEavg as follows:

$$C_{area} = \rho \times W \times SE_{avg} \tag{2}$$

The 5th percentile user spectral efficiency is the 5% point of the cumulative distribution function (CDF) of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz.

The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

With Ri (Ti) denoting the number of correctly received bits of user i, Ti the active session time for user i and W the channel bandwidth, the (normalized) user throughput of user i, ri, is defined according to equation (3).

$$r_i = \frac{R_i(T_i)}{T_i \cdot W} \tag{3}$$

The 5th percentile user spectral efficiency is evaluated by system level simulation using the evaluation configuration parameters of Indoor Hotspot-eMBB in Section 2.

Specific assumptions (e.g. duplexing schemes, antenna configurations, etc.) are followed by 3GPP TR 37.910 and the results for calculation and evaluation presents in Table 5.

Table 5: Calculation and Evaluation Results for Indoor Hotspot-eMBB test environment

Requirements[(1)]	DL or UL	Required value	Value [(2)]	Comments
Peak data rate (Gbit/s)	DL	20	21.1~140.2	The values are achieved by using 16 carrier aggregation.
	UL	10	16.6~64.6	
Peak spectral efficiency (bit/s/Hz)	DL	30	30.4~48.9	
	UL	15	18.2~25.8	
5th percentile user spectral efficiency (bit/s/Hz)	DL	0.3	0.31~1.18	For evaluation configuration B (30 GHz), Channel model A/B, with 12 TRxP and 36 TRxP.
	UL	0.21	0.23~0.48	
Average spectral efficiency (bit/s/Hz/ TRxP)	DL	9	9.4~19.91	For evaluation configuration B (30 GHz), Channel model A/B, with 12 TRxP and 36 TRxP.
	UL	6.75	6.9~11.44	
Area traffic capacity (Mbit/s/m^2)	DL	10	10.06~16.81	For evaluation configuration A (4 GHz), Channel model A/B, with 12 TRxP and 36 TRxP.
	UL	10	10.22~22.76	For evaluation configuration B (30 GHz), Channel model A/B, with 12 TRxP and 36 TRxP.

(1) As defined in Report ITU-R M.2410-0.
(2) According to the evaluation methodology specified in Report ITU-R M.2412-0.

As above result, peak data rate and spectrum efficiency requirements for Indoor-Hotspot-eMBB met with IMT-2020 requirement. However, mmWave technology can be used outdoor coverage scenarios such as high-rate hot-spots with traditional LTE/LTE-A base stations, high-rate areas and large area with new generation mixed mobile network in an urban environment including traditional LTE/LTE-A base stations and a small number of mmWave small-cells which provide almost full coverage in the area [12].

In order to implement and spread of new 5G mobile communication, further evaluation for environment of Dense-Urban-eMBB in mmWave is essential and will be considered in our future study.

CONCLUSIONS

In this paper we gave an overview over the fundamentals of IMT-2020 which will be the 5th mobile systems include new radio interface using mmWave which support the new capabilities of systems beyond IMT-Advanced. Based on investigation and analysis of technical performance requirements and evaluation methodology of IMT-2020, candidate technology and whether it meets with IMT-2020 requirement was presented. The Indoor Hotspot-eMBB scenario is one of the important components for evaluating IMT-2020 performance since the small cell using the mmWave band can improve the data rate significantly. For more performance evaluation, it is necessary to evaluate IMT-2020 Dense Urban-eMBB scenario in mmWave bands.

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