5G Radar: Scenarios, Numerology and Simulations

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***Abstract*—In this paper, we study the future 5G radar that uses the same transmit energy and the same spectral efficient multicarrier waveform for both radar sensing and communication. The technique is an interesting tool to open at the same time access to radio bands assigned traditionally either for radar or communication. The regulation status is first given, and then automotive, marine and aviation scenarios are presented. The numerology for the 5G radar is derived, and we show that the radar resolution requirement for adaptive cruise control is achieved with the radio band of 400 MHz. When the effective isotropic radiated power is 20 dBm, the operation ranges at the 60 GHz for radar and communication are 90 and 150 m, respectively. To maximize technology commonalities, a joint receiver for radar parameter estimation and timing synchronization is presented. The simulation results show that coarse range and velocity estimates are achieved in terms of the mean square error.**

Keywords—5G, radar, algorithm, estimation, synchronization

I. INTRODUCTION

Autonomous vehicles, vessels and planes are aimed to save lives and reduce accidents, and they use increasingly environmental sensors and communication techniques [1]. In public safety and military operations, real-time situational awareness is important during both peace and conflicts. Among the sensors, the radar is a key technology in early warning and surveillance systems, and the radars can operate reliably in all weather conditions and at all hours. The radar is also computationally lighter than camera, and uses much less data than high-resolution and expensive light detection and ranging (LiDAR). The fifth generation (5G) and larger available bandwidth at mmWave allow an ultra-low latency connectivity and a finer radar range resolution, respectively. Being a key enabler for the mmWave 5G, the high directivity antennas of narrow beam mean also small angular resolution. Beamforming is also a simple physical layer (PHY) security technique by focusing the transmitted energy to a desired target. In this paper, we will consider joint radar and communication in order to build the world's first 5G radar. The proposed 5G radar will use the same waveform for both radar sensing and communication, and therefore, energy and spectrum efficiency can be increased. The 5G radar differs from the cognitive communication or cognitive radar [2] where, either communication or radar system acts as a secondary user, and can temporarily borrow frequency bands from primary users. Therefore, an important advantage of the 5G radar is that it may open at the same time access to all radio frequencies assigned traditionally either for communication or radar services. Especially, there is a need to ensure adequate spectrum for both radar and military communication when the 5G visions will require more new and larger frequency bands.

According to our best knowledge, there is no joint radar and communication solution for the 3rd generation partnership project (3GPP) fourth generation (4G) either. A recent literature review for the joint radar and commercial communication is given in [3], and the existing demonstration systems are summarized in [4]. Many systems are designed in an ad hoc fashion and parametrization does not meet any communication standard. The Institute of Electrical and Electronics (IEEE) 802.11 systems are studied in [5]. In general, radar technology has not developed as fast as telecommunication techniques over the last 20 years [3]. The 5G and beyond will provide tremendous opportunities for radar concepts, and it can be foreseen that the radar applications in autonomous systems will grow very strongly in the coming decades. Maximization of technology commonalities between radar and communication is a key factor for rapid uptake of any new systems and standards.

The paper is organized as follows. First, the standardization and regulation issues are discussed. Then possible scenarios and the numerology for the 5G radar are presented with the simulation results. Finally, conclusions are drawn.

II. FREQUENCY REGULATION

The 5G Release 15 is the first 5G standard. The 5G new radio (NR) divides the frequency bands into two frequency ranges where the frequency range 1 (FR1) includes all existing and new bands below 6 GHz. The frequency range 2 (FR2) includes for one new bands in the range 24.25-52.6 GHz [6]. The low frequencies below 2 GHz correspond to existing LTE bands, with a maximum 20 MHz bandwidth. In the medium frequency range 3-6 GHz, the 100 MHz bandwidth is possible and the highest interest globally is in the range 3300-4200 MHz. Bandwidths up to 400 MHz are assumed in the higher frequencies, and the frequency range 24.25-29.5 GHz has paid the most attention so far. Finally, Table I presents the 5G NR frequency bands and main global regions above 2 GHz. In the table, the specific frequencies for the radar are similarly presented as defined by the international telecommunication union (ITU). The table includes also the IEEE short notations for describing the frequency band of operation, and historically they origin from radar engineering during the World War II [7].

TABLE I. RADAR AND 5G NR BANDS ABOVE 2 GHZ

<table>
<tr><th rowspan="2">IEEE frequency bands</th><th colspan="3">ITU radar bands</th><th colspan="2">3GPP 5G NR</th></tr>
<tr><th>Region 1 (Europe)</th><th>Region 2 (Americas)</th><th>Region 3 (Asia)</th><th></th><th>Region</th></tr>
<tr><td rowspan="2">S-band
2000-4000 MHz</td><td colspan="3">2300-2500</td><td rowspan="2">1920-1980, 2110-2170
2496-2690
2500-2570, 2620-2690
2570-2620
3300-3800</td><td rowspan="2">Europe, Asia
US, China
Europe, Asia
Europe
Europe, Asia</td></tr>
<tr><td>2700-3600</td><td colspan="2">2700-3700</td></tr>
<tr><td rowspan="2">C-band
4000-8000 MHz</td><td colspan="3">4200-4400</td><td rowspan="2">3300-4200
4400-5500</td><td rowspan="2">Europe, Asia
Asia</td></tr>
<tr><td>5250-5850</td><td colspan="2">5250-5925</td></tr>
<tr><td>X-band
8-12 GHz</td><td colspan="3">8.5-10.68</td><td></td><td></td></tr>
<tr><td>Ku-band
12-18 GHz</td><td colspan="3">13.4-14.0
15.7-17.7</td><td></td><td></td></tr>
<tr><td rowspan="2">K-band
18-27 GHz</td><td colspan="3">24.05-24.25</td><td rowspan="2">24.25-27.5</td><td rowspan="2">Global</td></tr>
<tr><td></td><td>24.65-24.75</td><td></td></tr>
<tr><td>Ka-band
27-40 GHz</td><td colspan="3">33.4-36.0</td><td>26.5-29.5
37.0-40.0</td><td>Global</td></tr>
<tr><td>V-band
40-75 GHz</td><td colspan="3">59-64</td><td></td><td></td></tr>
<tr><td>W-band
75-110 GHz</td><td colspan="3">76-81
92-100</td><td></td><td></td></tr>
</table>

Concerning the radar sensing, the low frequencies below 2 GHz are preferred for the long-range radars (LRR) such as the secondary surveillance radar between the air traffic control and aircraft transponder. The primary surveillance radars operate at the S-band around the airspace surrounding the airport. The X-band is used for aeronautical radiolocation, and in maritime, radars are used for using navigation and obstacle detection. Because of higher bandwidth available, the X-band radar is more accuracy than the S-band one, but it is more sensitive to weather condition like rain. Radars operating at higher frequencies can assist ships when arriving at the port and leaving the port. The bands at the 5 GHz are considered for cognitive communication [8]. For example, the licensed assisted access (LAA) is a spectrum-sharing scheme defined in the 3GPP Release 13, and it ensures coexistence with the radar. The IEEE 802.11p based V2X communication operates also at the 5.9 GHz band for intelligent transport systems (ITS). Overall, there is a 7 GHz unlicensed band at the 60 GHz, and the European Conference of Postal and Telecommunications Administrations (CEPT) [9] has explicitly harmonized the use of the band 63-64 GHz for future ITS applications such as the joint radar and communication. The aim is to reduce the number of traffic fatalities and to improve the efficiency of traffic. At the 24 GHz, there are a narrow 200 MHz band and a larger 5 GHz ultra-wide band (UWB) temporarily allowed for automotive short-range radars (SSR). However, there are potential interference from radio astronomy and satellite services, and therefore, the 77-81 GHz band is designed for long-term solution. The 76-77 GHz band is also used nearly worldwide for vehicular LRR providing safety features. In the US, the Federal Communications Commission (FCC) has already expanded the entire 76-81 GHz band for car radars.

III. 5G RADAR SCENARIOS

A. *Vehicle 5G radar*

An envisaged vehicle scenario for the 5G radar is illustrated in Fig. 1. In the figure, the left-hand source vehicle transmits 5G signal to a right-hand target vehicle receiver and uses the echo from target vehicle to derive the range, velocity and angular estimates at the source receiver. Figure also shows that one key enabler for the joint radar and communication is the vehicle-to-everything (V2X) communication, which allows a vehicle to communicate with other vehicles, pedestrians, roadside units as well as with the Internet, and cloud-based applications. Cooperative adaptive cruise control (ACC), platooning and road safety service via infrastructure are widely accepted use cases of the V2X.

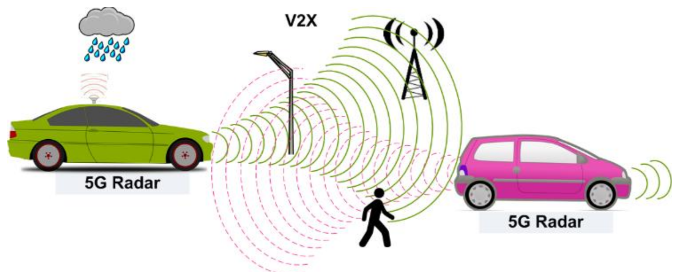

Fig. 1. The 5G radar is sensing and communicating at the same time and at the same frequency band.

The V2X is introduced in the Release 14 of the 3GPP, and the 5G enhanced V2X [10] is expected to enable very high throughput, high reliability, low latency and accurate positioning use cases. It will also enable extended sensors where vehicles could exchange sensor information locally. In general, data transmission requirements varies from few kbps of sensor data informing status of engines and mechanical parts up to few Gbps for 3D maps [1]. For the 5G the targeted peak data rate is 20 Gbps [11]. The link distances will be, however, limited depending on the frequency range, quality of the channel, and on the availability of beamforming. Self-driving requires also robust real-time data interaction. The targets of the 5G include 99.999 % and 1 ms for reliability and latency. For comparison, the 4G systems can offer reliability of 99.99 %, and the actual delays in the data link layer are in the order of 50-300 ms. Security and privacy are critical design factors when enhancing the 5G radar for mission critical applications such as the communication and sensing between the unmanned ground vehicles (UGVs). Beyond the beamforming, one approach for improving security is to exploit the PHY characteristics of radio transmitters and the wireless channel.

B. *Marine 5G radar*

Fig. 2 illustrates that the 5G radar is also a candidate for short-range ship-to-ship communication. A growing volume of shipping traffic needs reliable sensing in extreme weather conditions such as at the Artic, or areas where no or limited communication infrastructure exists. Unmanned surface vessels (USV) are widely used in ocean research, coast guard and defense force applications. For example, autonomous port approach and departure require accurate sensing with very low delays in the connectivity both inside and outside the ship [1]. According to the 3GPP Release 16 [12], and with appropriate power and antenna configuration, the ship-to-shore coverage can be enhanced up to 100 km with the LTE 800 MHz. Similar ranges can be achieved with the very high frequency (VHF) radios for distress communication. However, the available narrow band at lower frequencies means worse resolution for the radar. Beyond terrestrial communications, geostationary (GEO) satellites are in an orbit over the equator and they can practically provide coverage only up to 76° north. Low earth orbit (LEO) satellites have limited data rate of few kbps, and they feature larger Doppler and propagation delay than the terrestrial systems [13]. Accurate and reliable Global Navigation Satellite System (GNSS) positioning poses also challenges at the Artic. Data fusion with the 5G radar and other sensors increase positioning accuracy and safe navigation.

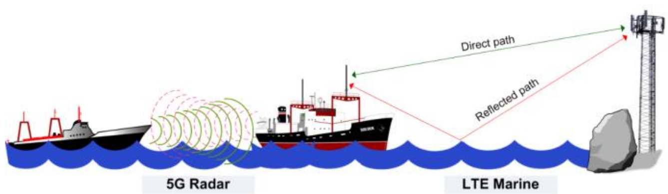

Fig. 2. The 5G radar with the LTE Marine communication.

C. Aviation 5G radar

Finally, Fig. 3 presents plane-to-plane and plane to ground scenarios for the 5G radar. Especially, flight safety in landing and take-off require both accurate sensing and real time communication between the plane and flight control. Unmanned aerial vehicle (UAV) assisted 5G radar can have numerous use cases in natural disasters and rescue operations where radars can work reliably in bright sunlight, darkness, rain, fog and dust. Helicopters operating [14] in unknown areas and degraded visual conditions are other examples.

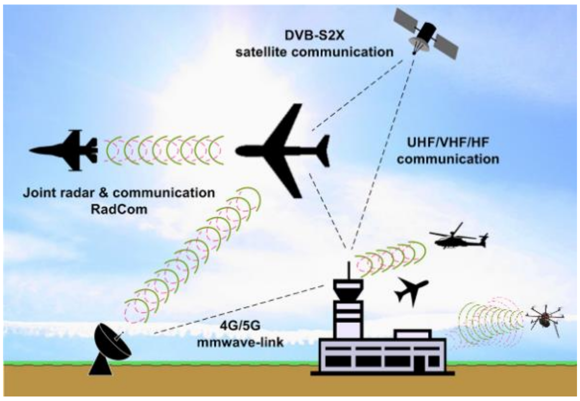

Fig. 3. Aviation scenarios for 5G radar.

IV. 5G RADAR NUMEROLOGY

The radar can measure the range, velocity and angular position of surrounding objects, and we will next consider what kind of radar resolution the 5G NR numerology allows. For comparison, typical long-range ACC [15] and helicopter [14] landing and take-off resolutions are given in Table II. For calculations, the 60 GHz frequency range is assumed as proposed by the CEPT [9].

TABLE II. RADAR RESOLUTION REQUIREMENTS

Resolution	AAC	Helicopter
Range, ΔR	< 0.5 m	< 3 m
Velocity, Δv	< 0.6 m	0.5-1 m/s
Angular, $\Delta\theta$	±15°	±7°

A. Radar range resolution

The multicarrier orthogonal frequency division multiplexing (OFDM) is a modulation method of modern communication technologies, and compared to the long-term evolution (LTE) based 4G, the 5G new radio (NR) includes scalable subcarrier spacing Δf [16]. The flexible parametrization and larger available bandwidth at mmWave means finer range resolution for radar as illustrated in Table III. In general, the range resolution is the ability of radar to distinguish two or more targets at different ranges, and it is determined as

$$\Delta R = \frac{c}{2B} \tag{1}$$

where c is the speed of light and B is the bandwidth. In the table, the range resolutions are calculated according to the transmitted (TX) signal, and the bandwidth efficiency is designed to be up to 99 %. As discussed in the context of Table 1, the maximum bandwidths at the frequency ranges 3-6 GHz and above the 6 GHz are 100 MHz and 400 MHz, respectively. These bandwidths correspond the minimum range resolution values 1.5 m and 0.4 m in Table 3. Finally, comparing the values with the requirements in Table 2, we can said that the needed helicopter and ACC resolutions can be achieved with the bandwidths 50 MHz and 400 MHz, respectively.

The 5G NR Release 15 frequency ranges, as presented in Table 1, may be extended or complemented by the 3GPP in future releases [6]. In addition, the terahertz is envisaged to be the key technology for the forthcoming high-capacity sixth generation (6G) communication and ultra-wideband sensors. On the other hand, and understanding the fact that the regulation is a time consuming process, the joint radar and communication technique may open at the same time access to all radio frequencies assigned traditionally either for communication or radar services. Considering the 5G radar at the 63-64 GHz band for future ITS applications, the range resolutions 0.2 m can be achieved as shown in Table III. Similarly, the 77-81 GHz band for vehicle radars would allow a resolution 0.05 m.

TABLE III. THE 5G NR AND RANGE RESOLUTIONS

	Subcarrier spacing Δf [kHz]	TX/CH bandwidth B [MHz]	Range resolution ΔR [m]
LTE	15	18/20 (90%)	8.3
5G NR	30	49.5/50 (99%)	3.0
5G NR	60	99/100 (99%)	1.5
5G NR	120	198/200 (99%)	0.75
5G NR	240	396/400 (99%)	0.40
5G NR	480	792/800 (99%)	0.20
5G NR	960	1584/1600 (99%)	0.10

B. Radar velocity resolution

In the wireless mobile communications, the performance degradation due to the maximum Doppler shift

$$f_D \approx \frac{v}{c} f_c \tag{2}$$

becomes more significant when the carrier frequency f_c and the velocity v increase. The Doppler shift and coherence time are inversely proportional to one another as

$$\tau_D \approx \frac{1}{f_D}, \tag{3}$$

and in a slow fading channel, τ_D is much larger than the OFDM symbol period $T_{\mathrm{OFDM}} = 1/\Delta f$. Finally, by taking into account the round-trip time (RTT) to a target and back, the radar velocity resolution [17] can be determined as

$$\Delta v = \frac{c}{2\tau_D f_c}. \tag{4}$$

Comparing the ACC and helicopter velocity resolution requirements in Table II and the subcarrier spacing values in Table III, we can observe that $\tau_D >> T_{\mathrm{OFDM}}$.

C. Radar angle resolution

Being a key enabler for the 5G, multiple-input and multiple-output (MIMO) antenna beamforming improves the link budget and coverage at higher frequencies. The larger the number of individual antenna elements, the higher the directivity and the narrower the beam can be achieved. The narrow beam means small angular resolution $\Delta\theta$ for the radar, and in general, the angular resolution equals to half-power (-3 dB) bandwidth $\theta_{3\mathrm{dB}}$. Typical ACC and helicopter angular resolution requirements are presented in Table II. The radar cross range resolution Δ_{RCR} is illustrated in Fig. 4, and it is an ability of radar to differentiate multiple objects at the same range. With the sufficient small $\theta_{3\mathrm{dB}}$ we can write as

$$\Delta_{\mathrm{RCR}} \approx R\,\theta_{3\mathrm{dB}}. \quad (5)$$

The angular resolution is a challenge for small-sized radar since it directly depends on the area or effective aperture of the radar antennas. However, high-resolution direction of arrival (DOA) estimation algorithms such as the multiple signal classification (MUSIC) can overcome the size limitation [18].

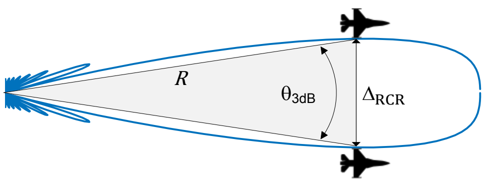

Fig. 4. The radar angular and cross range resolutions.

V. 5G RADAR RECEIVER

A. Range and velocity estimation

In both the 5G NR and the LTE, there is a 10 ms radio frame, and it is divided into ten 1 ms subframes [16]. The subframe is in turn divided into slots of 14 consecutive symbols, and the duration of a slot in milliseconds depends on the numerology. As Fig. 5 shows, symbol-timing adjustment is realized by detecting the primary synchronization signal (PSS). The time domain PSS correlator can be used for range estimation, too. In a frequency domain, the PSS is m-sequence of length 127, and it relaxes the time and frequency offset ambiguity problem of 63-length Zadoff Chu sequence used in the LTE. In the LTE, the PSS periodicity is also fixed, but the 5G NR has a specific synchronization signal block (SSB) of 4 symbols, and bursts of SSBs are transmitted in different patterns depending on subcarrier spacing and frequency range. For the radar, the SSB interval determines the maximum RTT.

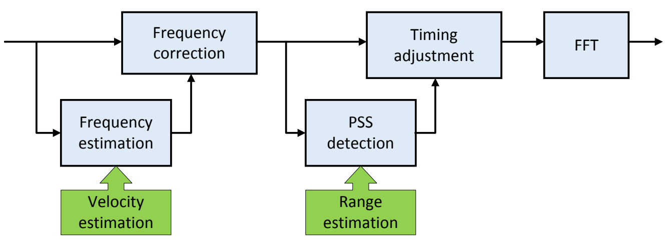

Fig. 5. A correlator based receiver for joint radar and communication.

The threshold for peak detection can be given as

$$\gamma_T = \sqrt{\sigma^2 \ln\left(\frac{1}{P_{\mathrm{FA}}}\right)} \quad (6)$$

where P_{FA} is the probability of false alarm and σ^2 is the variance of the complex-valued zero-mean additive white Gaussian noise [19]. At the correlator-based receiver, there is a trade-off between the P_{FA} and probability of detection P_D, and a very accurate approximation can be given as

$$P_D \approx \frac{1}{2}\mathrm{erfc}\left(\sqrt{-\ln(P_{\mathrm{FA}})} - \sqrt{\mathrm{SNR}+0.5}\right). \quad (7)$$

The P_D curves as a function of the signal-to-noise ratio (SNR) for several values of P_{FA} are presented in Fig. 6.

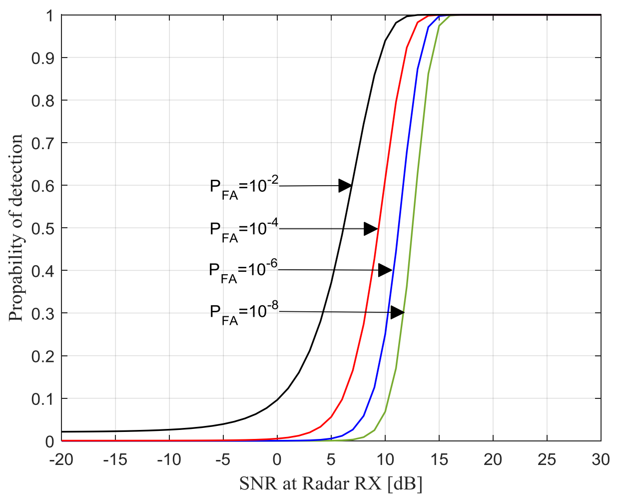

Fig. 6. P_D as a function of the SNR for several values of P_{FA}.

When the correlation peak is detected, the range R is equal to the round-trip time τ to object and back as

$$R = \frac{c_0\,\tau}{2}. \quad (8)$$

In practice, the frequency offset has, however, a profound impact on the autocorrelation property, and it need to be corrected before the PSS detection. In more detail, when the PSS peak is detected, the radar velocity estimate is calculated using the frequency estimate. The frequency estimation is based on the cyclic prefix (CP) correlator as shown in Fig. 7. In the estimator, there is first a correlation between the OFDM signal and its fast Fourier transform (FFT) length N delayed version. Then the signal is integrated across part of the CP, and averaged across part of the slot. The phase ϕ from the strongest correlation peak is used to estimate frequency as

$$f_e = \frac{\phi\,\Delta f}{\pi}, \quad (9)$$

and finally, the velocity can be estimated as

$$v = \frac{c f_e}{2 f_c}. \quad (10)$$

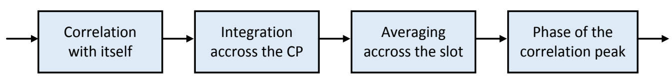

Fig. 7. Using frequency estimation for radar velocity estimation.

VI. 5G RADAR PERFORMANCE

A. Range and velocity accuracy

In general, any measurement made with a basic resolution ρ will have a mean-square (MSE) error [17] as

$$\delta_{\mathrm{MSE}} \cong \left|\frac{\rho}{\sqrt{2SNR}}\right|^2, \qquad \mathrm{SNR} >> 0. \qquad (11)$$

By replacing ρ with ΔR (1), Δv (4) and Δ_{RCR} (5) radar range, velocity and cross range accuracies can be determined. Fig. 8 illustrates the theoretical and measured MSE results for the range estimation. The presented results meet each other. In general, the simulation model is based on the principle shown in Fig. 5 without frequency error and synchronization loop. The threshold (6) for peak detection is determined by using $P_{\mathrm{FA}} = 10^{-6}$. In this paper, we assume N is 2048, and in practice without oversampling, there is one-half sample interval $\pm T_s/2 = \pm 1/(2\Delta f N)$ uncertainty around the peak of correlation causing a saturation limit for the range accuracy

$$\delta_{\mathrm{sat}} \cong \left|\frac{c}{4\Delta f N}\right|^2, \qquad \mathrm{SNR} >> 0. \qquad (12)$$

Increasing the length of the PSS sequence, better MSE results can be achieved, especially at low SNR values. On the other hand, the presented simple range estimator in Fig. 5 can be considered as a coarse range estimation technique, and a separate fine estimation technique is under study as in the case of the IEEE 802.11 radar [5].

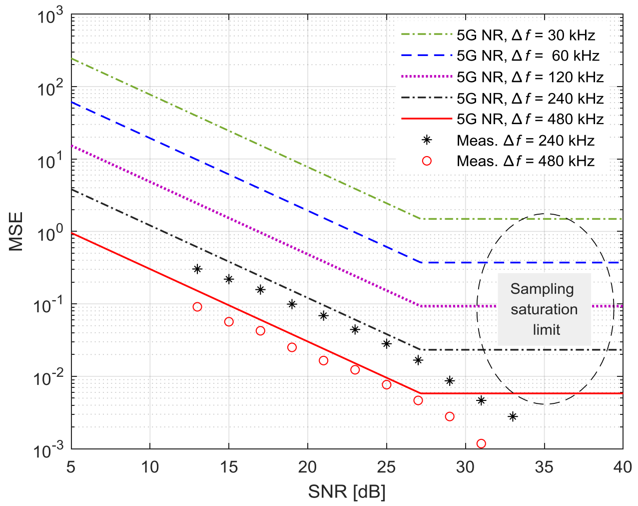

Fig. 8. 5G radar MSE for the range estimation.

Fig. 9 presents the MSE results for the velocity estimation according to the principle, presented in Fig. 7. The length of the CP [6] is

$$T_{\mathrm{CP}} = \frac{9}{128\Delta f}, \qquad (13)$$

and the number of averaged symbols A_S in the slot is 7. In the simulations, the phases ϕ (9) are further filtered with a simple infinite impulse response (IIR) low pass filter to smooth the results. The IIR filter time constant I_{IIR} is 16, and the IIR filter settle time is about four [20] IIR time constants. For the reference curves, the parameter τ_D in (4) is determined as

$$\tau_D = 4 I_{\mathrm{IIR}} T_{\mathrm{CP}} A_S. \qquad (14)$$

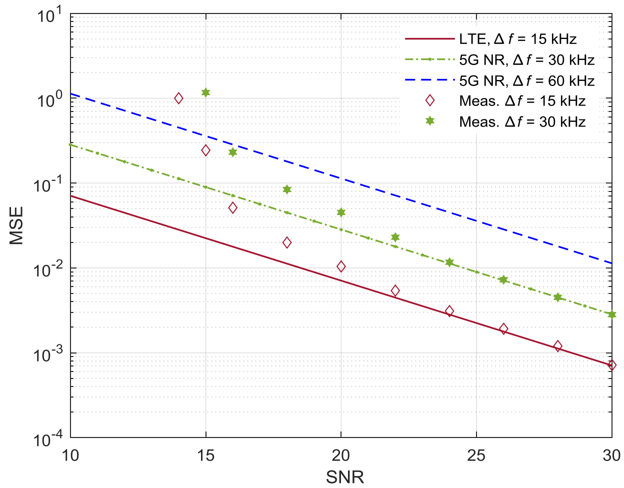

Fig. 9. 5G radar MSE for the velocity estimation.

In contrast to range resolution (1), the velocity resolution (4) decreases when the subcarrier spacing Δf increases in (13) - (14). As the simulation results show, the best velocity accuracy can be thus achieved with the LTE subcarrier spacing. The results indicate also that SNR higher than 15 dB is required for velocity estimation. The better results can be achieved by increasing the IIR filter time constant with a longer settle time.

B. Range in free space loss

Fig. 10 shows the achievable ranges R for the radar and communication at the 60 GHz. With the assumption of the free space loss, the SNR at the radar and communication receivers can be given as

$$SNR_R = \frac{\mathrm{EIRP}\; G_{\mathrm{RX},R}\, G_{P,R}\, \sigma_{\mathrm{RCS}}\, c^2}{kT_0 B N_F\, (4\pi)^3 R^4\, f_c^2} \qquad (15)$$

$$SNR_C = \frac{\mathrm{EIRP}\; G_{\mathrm{RX},C}\, c^2}{kT_0 B N_F\, (4\pi)^2 R^2\, f_c^2} \qquad (16)$$

where k is Boltzmann's constant and T_0 is the standard noise temperature 290 K. We assume 400 MHz band B for the 5G NR, and the other parameters are determined in Table IV. The EIRP limit is set by the CEPT. The RCS is a measure of the incident power intercepted by the target and radiated back towards the radar [17]. The RCS depends on target's size, material and shape as well as on the frequency and polarization of incident wave and angle of that and reflected wave. Typical RCS values for the pedestrian and the vehicles are -10 and 20 dBms, respectively. In a correlator-based radar receiver, an additional processing gain $G_{P,R}$ can be assumed, and now it corresponds the FFT length N is 2048.

TABLE IV. RANGE COMPARISON PARAMETERS

General parameters		
f_c	Carrier frequency	60 GHz
B	Total bandwidth	400 MHz
EIRP	Effective isotropic radiated power	20 dBm
G_{RX}	Receiver antenna gain	20 dBi
N_F	Noise figure	7 dB
σ_{RCS}	Radar cross section (RCS)	-10, 20 dBsm
$G_{P,R}$	Radar processing gain	31 dB

With the assumption that the channel decoder will reduce the error rate to the final target value, the required SNRs for the uncoded binary phase shift keying (BPSK) and 64-ary quadrature amplitude modulation (QAM) are 7 dB and 15 dB at the bit error rate (BER) 10^{-3} [21]. Therefore, and as the Fig. 10 shows, the achieved ranges for the 5G NR 64-QAM and BPSK are 70 m and 150 m, respectively. If we experimentally increase the transmit EIRP up to 40 dBm according to the FCC, the corresponding communication ranges are 400 m and 650 m.

In the case of the radar, the achievable range corresponds the RTT. Due to the additional radar processing gain $G_{P,R}$, the radar range exceeds the communication range at high SNR. As illustrated in Fig. 6, there is a trade-off between the P_{FA} and P_D in the correlator-based threshold receiver. When the vehicle is detected with a high probability 99.999% and at a low false alarm rate $P_{\mathrm{FA}} = 10^{-6}$, ranges up to 90 m can be achieved.

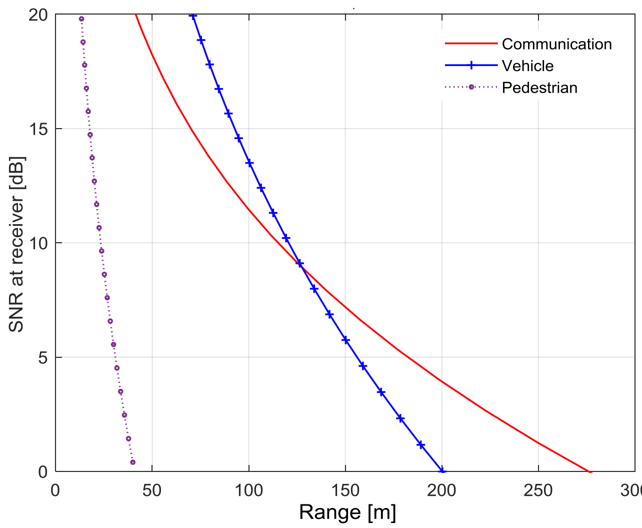

Fig. 10. 5G NR radars at 60 GHz.

VII. Conclusions

In this paper, we considered the 5G radar that uses the same transmit energy and the spectral efficient OFDM waveform for both radar sensing and communication. The frequency regulation was first summarized since the joint radar and communication is an interesting tool to open at the same time access to radio bands assigned traditionally either for radar or communication. The CEPT has already dedicated a 1 GHz band at the 60 GHz for future ITS applications, which are also use cases for the 5G radar. Consequently, automotive, marine and aviation scenarios were envisaged. We derived that the ACC range resolution requirement is achieved with the NR band of 400 MHz. The related operation ranges for vehicle radar and communication are 90 and 150 m, respectively. Maximization of technology commonalities is a key factor for rapid uptake of any new systems and standards. Therefore, a joint receiver for radar parameter estimation and timing synchronization was presented. The reference curves were derived to analyze the MSE performance and the simulation results show that coarse range and velocity estimates are achieved. A fine tune estimator is under study. In joint radar and communication devices, a research challenge is also to ensure high enough isolation between the transmitter and receiving channels. The transmitter leakage reduces signal to interference plus noise ratio and can saturate the receiver and mask weak radar targets.

VIII. Acknowledgements

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