Technologies for Efficient Amateur Drone Detection in 5G Millimeter-Wave Cellular Infrastructure

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Abstract*—Unmanned aerial vehicles also named drones are recently gaining increased research attention across various fields due to their flexibility and application potential. Steady increase in the number of amateur drones demands more stringent regulations on their allowed route, mass, and load. However, these regulations may be violated accidentally or deliberately. In these cases, spying with drones, transfer of dangerous payloads, or losing reliable drone control can represent a new hazard for people, governments, and business sector. The technologies to detect, track, and disarm possible aerial threat are, therefore, in prompt demand. To this end, ubiquitous cellular networks, and especially fifth-generation (5G) infrastructures based on the use of millimeter-wave radio modules, may be efficiently leveraged to offer the much needed drone detection capabilities. In this work, we propose to exploit the 5G millimeter-wave deployment to detect the violating amateur drones. We argue that the prospective 5G infrastructure may provide with all the necessary technology elements to support efficient detection of small-sized drones. We, therefore, outline a novel technology and system design perspective, including such considerations as the density of base stations, their directional antennas, and the available bandwidth, among others, as well as characterize their impact with our ray-based modeling methods.

I. DETECTION OF UAV WITH 5G INFRASTRUCTURE

A. *Advent of amateur drones*

Initially exploited by the military, unmanned aerial vehicles (UAVs) are currently gaining increased interest from civilian users because of rapid development in electronics. A flying device without a human pilot on board, UAV or simply a drone is a flexible solution suitable for a broad range of applications, such as goods delivery, video monitoring, and aerial mapping, among many others. In fact, drones become so popular that Federal Aviation Administrations (FAA) in the US demanded mandatory registration for new drones as well as restricted any commercial use of them until thorough regulations are issued. It was estimated that by 2018 the number of commercial drones in the air will reach about 600,000 [1].

Today, the research and industry communities are working intensively to facilitate more reliable and flexible drone utilization. A number of technical issues, such as collision avoidance, battery life optimization, reliable connectivity with fixed ground infrastructure (backhaul), and safe take-off and landing, are yet to be solved and thus slow down the mass employment of drones [2], [3]. However, we are approaching the time when the remaining challenges are solved and the fleets of drones will be flying around the city. The use of UAVs might introduce impressive benefits, but there are also some pitfalls related to their flexibility and the absence of a pilot. Along with responsible drone operators abiding by the regulations, there may be other ones offending against law accidentally or intentionally.

The first type of possible violations includes, for example, anti-social and terrorist acts, while the second type can be attributed to non-acquaintance of regulatory laws. The latter also includes the cases where a partially out-of-order drone behaves unpredictably due to spatial disorientation; so any drone acting in a dangerous, unpredictable, improper, or unsafe manner towards other drones, infrastructure, or humans, is to be considered an air traffic law violator. Therefore, it is extremely important to be prepared for any inconvenience caused by violating the rules for usage of drones. Undoubtedly, early detection of violating drones is among the key elements of aerial accident prevention.

In the scope of this work, we focus on *fast detection* of amateur drones (ADr) that might be launched from the ground close to drone-free regions of an urban scenario. In particular, we assume that ADr might belong to any organization (including illegal, non-certified and, in the extreme, terrorist) or any private operator and carry arbitrary payload, including chemical and explosive substances, as well as various on-board equipment. It might also not carry any on-board systems at all, thus preventing communication and control takeover by a third-party neutralization system. The problem statement is then more complicated, since the ADr is a potential source of the highest level of threat for other drones as well as national institutions and assets, and it should be neutralized as fast as possible.

B. *UAV in next-generation cellular*

Approaching their initial test deployments, the fifth generation of wireless networks, 5G, is planned to be initially tested in 2018, Seoul, Korea. As 5G broadly represents an umbrella for various technology types, there is room for drones in the future 5G scenarios [4]. According to the latest use case descriptions, drones can be utilized to extend network coverage in highly crowded areas as well as provide emergency coverage in situations of local infrastructure malfunction or disaster. Despite intensifying discussions on applying UAVs to extend radio coverage in future wireless systems, integration of drones into current network infrastructure and human environment still remains an open issue. The important problems of controlling, detecting, tracking, mitigating interference, and optimizing radio resource management [5] need to be resolved before the fleets of drones can fly around freely.

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Employing the so-called millimeter wave (mmWave) frequency bands, 5G cellular promises to unlock unprecedented available bandwidths, allowing to support such advanced and throughput-hungry multimedia applications as augmented reality and unmanned vehicle control. However, it has to be noted that due to specifics of the mmWave bands the 5G may not be able to rely on it entirely, thus conventional microwave (uWave) frequencies and related wireless standards will also remain a part of 5G technology [6]. As a result, 5G mmWave base stations (BSs) will soon be integrated into the traditional cellular infrastructure. Having in mind the unique capabilities of 5G, especially the increased bandwidth, we propose to employ some of the spare mmWave capacity to provide means for safe drone interaction with the human environment.

Particularly high frequencies at mmWave bands allow for improved detection of objects, thus effectively serving as a radar. Moreover, the anticipated densification of mmWave BSs, which is important to provide session continuity and improved capacity, should ensure more reliable drone detection as well. We reiterate an important fact that the time to react before potential damage is always limited; hence, fast and reliable detection of violating drones is of extreme importance. Therefore, in this work, we envisage a novel system for early detection of violating drones by employing the powerful 5G mmWave capabilities.

II. CHALLENGES POSED BY UNAUTHORIZED DRONES

As soon as all the necessary regulations are in place and substantial UAV traffic is permitted in the human environment, the question of public safety is due to become crucial. Every functionality of drones aimed to aid people, such as video monitoring or cargo delivery, could then be potentially misused. For instance, drones carrying cameras already violate privacy by monitoring humans without any permission. Further, cargo delivery could pose a major threat in case the payload turns out to be harmful. Therefore, a number of challenges arise that should be considered before an ultimate permit for ADr to operate freely is issued. We distinguish four principal challenges related to the flight of an unauthorized drone, namely: detection, localization, tracking, and deactivation.

Even though every aspect in the above vision has importance and should be considered carefully, the primary challenge is fast *detection*, which becomes the focus of this work. Indeed, before a violating drone is detected it cannot be disarmed. For that purpose, single or multiple distributed detecting sensors [7] need to observe the flight of drones in real time. In addition, all these sensing nodes require an adequate cooperative algorithm for timely detection and identification of UAVs. Another problem to be solved is the *localization* of a drone. Being a highly mobile aerial node, a drone can easily disappear from sight. Hence, precise localization of drones needs to be made available to the authority responsible for drone surveillance and recent research pays particular attention to the drone localization techniques. Conventional methods employ mobile wireless sensor networks, but existing approaches are not fully suitable for accurate drone positioning because of the unique properties of the UAVs.

Alongside with localization, drone *tracking* is another emerging issue due to highly unpredictable 3D mobility patterns of drones. The goal here is to predict further behavior of the UAV by employing tracking algorithms. Since the countermeasures to prevent the violation caused by a drone cannot be taken immediately, the subject drone should be tracked until it is disarmed. Subsequently, tracking is of special importance in order not to lose the drone from sight. The last but not least challenge is drone *deactivation*. It could involve such methods as drone jamming, hunting, etc. To date, numerous techniques for prevention of drone-inflicted damage have been proposed; however, in the worst case, drone deactivation can become a major issue on its own and inflict further damage to the human environment. It is extremely important to react promptly before any such damage is caused; thus, this challenge has to be solved with a proper, time-efficient and safe method.

In this article, we concentrate on techniques for ADr detection in urban environments. To this end, below we review the key technologies and offer examples based on existing equipment. It should be noted that almost all of these techniques were initially tested or adopted for military purposes, and now they are gradually propagating into civilian applications. For that reason, in the commercial market it is already possible to purchase such equipment with reduced (although not fully removed) restrictions on International Traffic in Arms Regulations (ITAR).

III. PRINCIPLES OF 5G DRONE DETECTION SYSTEM

Inspired by the promising 5G capabilities, we envisage that 5G mmWave infrastructures will be capable of supporting two functional modes: provisioning of communication services as well as detection of violating ADr based on multistatic radar techniques [8]. Indeed, as illustrated in Fig. 1, the detection system may partially reuse the elements of 5G mmWave infrastructure. At the same time, the level of sharing the 5G resources may depend on the capabilities of the network and wireless equipment, and not be restricted to the use of mmWave BSs. Based on flexible modular design, our proposed architecture offers versatile utilization and is ready to be adopted for novel communication and detection challenges by replacing certain elements of the system.

In our proposed architecture, multistatic radar transmitting (Tx) system generates a wideband signal into the upper hemisphere. The signal propagating in the site-specific area experiences intermediate interaction with the objects and reaches the receiving systems on multiple paths (named multipath propagation). In Fig. 1, a multistatic radar receiving (Rx) system is represented by a number (1,2...,N) of different mmWave BSs, each collecting its unique portion of the multipath components of the transmitted signal. It has to be emphasized that both Tx and Rx systems are located at some distance from each other. To synchronize cooperative operation of the Tx and Rx in the radar mode, a multiplexer triggers up single mmWave BS or groups of them, as soon as the Tx begins to radiate signal into space. Additionally, it may (de)activate a mmWave BS for smarter detection, in case one of them is blocked by an object or sends incorrect output data.

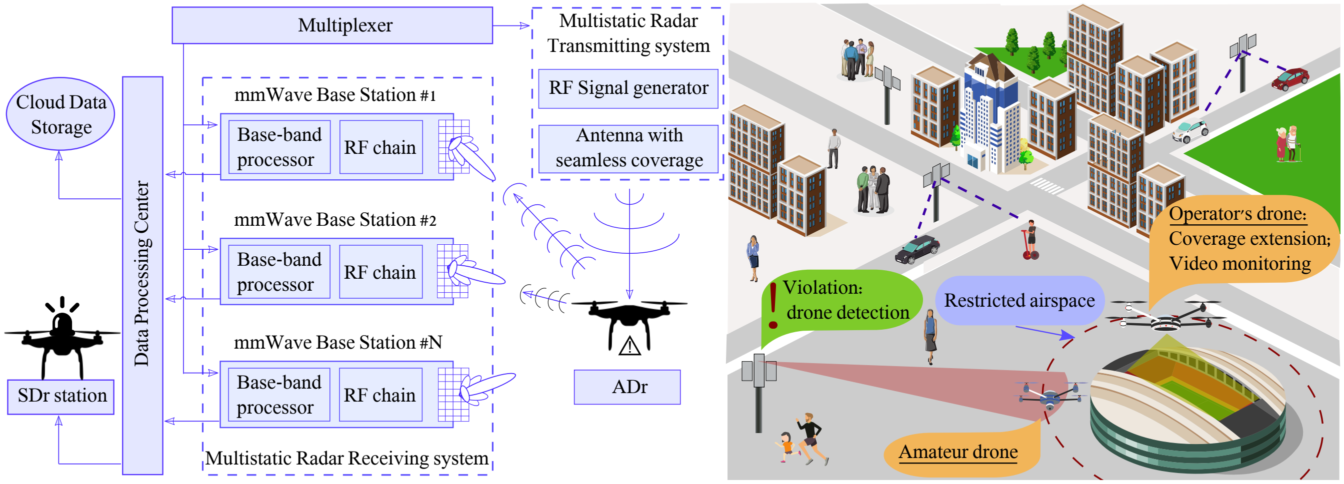

Fig. 1. Proposed 5G-based system architecture for detecting amateur drones (left) and envisioned motivating scenario (right).

Collecting and processing the output data from all (or some) of the mmWave BSs, Data Processing Center (DPC) controls the overall management of the radar system and predicts further actions. It may initiate an additional detection procedure to verify the current results, compare the collected information with the reference data patterns in Cloud Data Storage (CDS), or summon surveillance drones (SDr) to neutralize an intruder. Depending on the amount and the quality of received data, the DPC might detect and potentially recognize the type of the ADr as well as determine its intentions by comparing the collected information against past data stored in CDS. The DPC may also assign the level of threat to one or several detected drones by taking into account multiple probabilistic criteria assessed on-line.

IV. Enabling Technologies for Detecting Drones

This section discusses the necessary technology features to implement our target 5G-based ADr detection system.

A. *Use of mmWave bands*

Frequency band. According to current technology development plans, 5G will incorporate the previous generations of wireless solutions (3G and 4G) as well as introduce the new promising mmWave technology. Hence, there is a choice between two potential carrier frequencies for the intended radar application: uWave and mmWave bands. Owing to the shorter wavelengths of mmWave carrier, small objects in the propagation environment are almost invisible at uWave while remain visible (electrically large) in mmWave. It is, however, clear that the type of roughness and irregularities of reflecting surfaces becomes more significant in mmWave bands, whereas these effects are minor in uWave [9]. Such behavior offers an advantage for usage of mmWave frequencies in detecting miniature drones sized within a range of 0.2 – 1.0 m, which is typical for ADr.

To assess the detection capabilities of uWave and mmWave bands, we employ detailed modeling of radar cross-section (RCS), which demonstrates how an object scatters the incident electromagnetic radiation back to the Tx position [10]. Together with uWave and mmWave bands, two different geometric radii were considered: 0.4 m and 1.5 m. As observed in Fig. 2, the capability to detect small objects is x1000 times (30 dB) higher at mmWave (60 GHz) with respect to that at uWave (2 GHz) if the angle of incidence equals to 0°.

These results confirm a crucial advantage of mmWave in comparison to uWave for ADr detection. The RCS behavior in Fig. 2 can be explained by undermining of the reflected component, which is strong enough due to diffuse scattering and diffraction. Related to the unique properties of an object, the RCS is a base parameter that might be utilized as a measure to distinguish “drone” and “another drone” as well as “drone” and “not a drone”.

Bandwidth. Future 5G mmWave systems will not only support extremely high carrier frequencies but also effectively operate in wider bandwidths (up to 2 GHz). Wider bandwidth helps differentiate between the closely flying ADrs more accurately, since the pulses of shorter duration do not overlap each other at the receiver. The potential range resolution cell

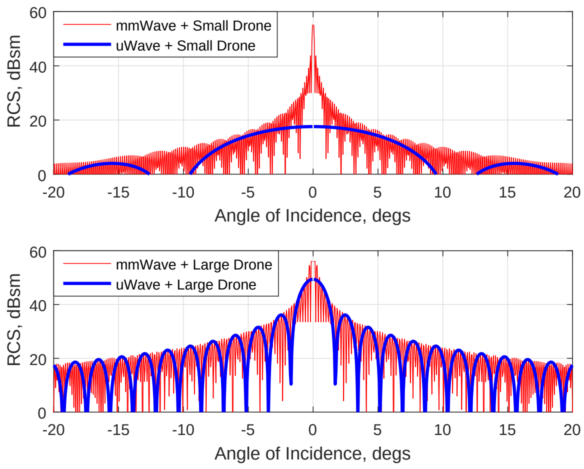

Fig. 2. Reflection from small and large drones in uWave (bottom image) and mmWave (top image).

of a radar system can be calculated as:

$$\Delta C = c/2B, \tag{1}$$

where ΔC is the range resolution, c is the speed of light, and B is the system bandwidth. Using this equation [10], it is possible to demonstrate that a system having 200 MHz of bandwidth (typical for uWave cellular technology) achieves the range resolution of 0.75 m, while 2-GHz bandwidth in mmWave gives us x10 higher precision (0.075 m).

B. Composition of receiving system

MIMO system. Multiple co-located decorrelated antennas on the Tx and Rx sides establish an efficient multi-input multi-output (MIMO) system that looks promising for future 5G communication. It creates additional channel diversity for the multistatic scheme and improves throughput via simultaneous transmission of multiple streams over different spatial channels. Subsequently, a multi-element antenna increases the effective bandwidth of the wireless channel. The receiving MIMO antenna array in mmWave BSs can also be reused for the purposes of multistatic radar functionality to receive the transmitted signal [11].

The MIMO radar system with co-located antennas can achieve higher spatial resolution and provide substantially improved immunity to interference as compared to the conventional technologies, such as phased arrays, where elements are fed by one RF chain. Utilization of all these advantages leads to unprecedented target detection levels, improves parameter estimation, as well as enhances tracking and recognition capabilities. Tentative results obtained with our custom-built ray-based modeler (Table I) demonstrate that utilization of MIMO functionality in mmWave BSs for radar applications improves detection probability in relation to single-input single-output (SISO) systems. The performance data has been collected for a single mmWave BS of interest when a number of scatterers and interfering transmitters around the target mmWave BS is generated randomly, with a certain characteristic density. When the level of interference caused by the scatterers and antennas is equal to or higher than the useful signal from the ADr, detection fails.

TABLE I
ADR DETECTION PROBABILITY USING MIMO AND SISO

#	System	Density of scatterers, m^{-2}	# of interfered BSs	Detection probability
1	SISO	0.05	1	0.59
2	SISO	0.25	3	0.35
3	MIMO	0.05	1	0.82
4	MIMO	0.25	3	0.71

Beamforming. Adjusting the phases and magnitudes of a signal coming to each element of the antenna array allows for producing different types of beam shapes. Two principal blocks are required to implement beamforming: an RF chain for controlling the phases and amplitudes and a baseband processor for handling the signals (see Fig. 1). Three conventional beamforming techniques are known today, namely: analog, digital, and hybrid [12]. The first architecture is built upon a single RF chain that controls multiple phase shifters feeding an antenna array. Despite the fact that analog beamforming is the most limited option, it also remains the cheapest and least complex technique [12], which is successfully exploited in indoor mmWave technology, including IEEE 802.11ad.

Another architecture is based on digital beamforming, which may potentially support as many RF chains as there are antenna elements. Applying suitable precoding yields higher algorithmic flexibility and may lead to better performance as compared to other beamforming architectures [12]. For example, multi-user coverage supported by the digital beamforming plays a crucial role in promoting the beamforming technology to become the best candidate for intended radar applications. However, higher complexity and stringent hardware requirements increase the total costs and energy expenditures, thus limiting the use of fully digital beamforming to high-end 5G BSs.

Combining the advantages of both analog and digital beamforming architectures [12], hybrid beamforming is also becoming available. Since the number of converters is significantly lower than the number of antennas, there are fewer degrees of freedom for the digital baseband processing. Therefore, the utilization of hybrid and analog beamforming architectures for the combined communication and radar applications remains questionable and requires further research.

Beamsteering. Since 5G mmWave communication is intended to support dynamic deployments, static beamforming may not offer sufficient reliability, as it cannot direct the main beam to the served user. To solve this problem, a beamsteering procedure can be applied in order to adjust the phases and magnitudes in real-time as well as keep the main beam directed at the served user. Once the system is equipped with a beamsteering technique for communication purposes, it becomes possible to achieve some benefits for the radar applications as well. In this case, due to the utilization of directive antennas, the beamsteering procedure may assist in detection of a violating drone through fast scanning.

Using a predefined number of phases per each antenna element, the scanning process allows to extend the beamspace for drone detection in a hemisphere. The localization can also be performed easily as soon as the violating drone is found with a scanning procedure. When such a drone is detected and localized, a tracking procedure is triggered in order to identify its parameters and intentions. This consecutive approach reduces the chances of false assessment of the threat, but it also requires more radio resources and smarter algorithms that may be more difficult to implement in relatively simple BSs.

C. Composition of transmitting system

Generally, the Tx system can comprise two main blocks: an RF generator and an antenna; the latter begins to radiate a signal upon being triggered by a multiplexer. The key technical requirements applied to the transmitting system are high power density and a pattern directed to the upper hemisphere. The first criterion is crucial since it characterizes the detection performance of the entire system, but remains limited by radio

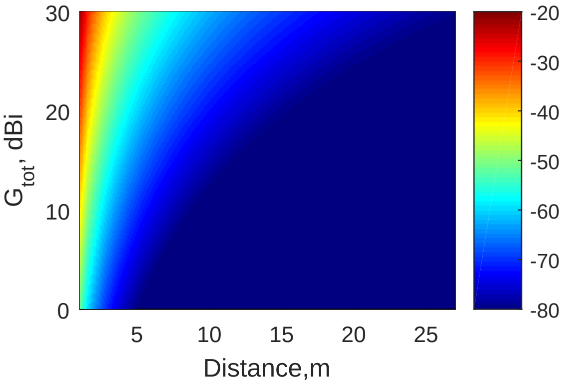

Fig. 3. Received power (color bar on the right) vs. distance and total gain. Dark blue region is the noise level equal to -80 dBm.

frequency regulations in all countries. The importance of the second criterion is in achieving uniform coverage across an area, where an ADr might potentially be detected.

To keep human safety at high levels, the antenna of the Tx system must be installed at the heights of at least 2 m. Recall that the electromagnetic mmWave field attenuates strongly when passing through concrete and brick walls (20 – 40 dB), and thus should not impact the health of humans inside buildings when keeping the power density below the level of 5 mW/cm^2 [13]. Based on these requirements, a simple and robust candidate for the antenna of the Tx system is a vertical dipole array.

To establish sufficient magnitude of the Tx system gain, it is important to first estimate the link budget. Here, the radar equation may be considered as a function of the distance and the total Tx and Rx gain $G_{tot} = G_{tx}G_{rx}$ as:

$$P_r(d, G_t) = \frac{P_t G_{tot} \lambda^2 \sigma}{(4\pi)^3 d^4}, \tag{2}$$

where P_t is the transmit power, λ is the wavelength, d is the distance to the drone, and σ is the RCS. The noise floor level for the considered 28-GHz carrier is set to 80 dBm by taking into account the $BW = 0.5$ GHz and the noise figure of 7 dB.

In light of the above and based on Fig. 3, the following important observations can be made. First, antenna gain in a radar system significantly improves the detection capabilities, even though the total received power reduces according to d^{-4} – faster than the total gain may compensate for it, since $G_{tx}G_{rx}$. Second, assuming practical magnitude gains of the antenna at the BS side as equal to 20-22 dBi, the antenna at the Tx side should have at least 8-10 dBi of gain (see Fig. 3), which is absolutely feasible to guarantee the detection range of up to 20 m.

D. DPC, controller, and CDS functionality

The main objective of the DPC in our architecture is to collect information from the mmWave BSs and process it at a later time. Data processing algorithms should employ not only standard formulations of signal processing but also specific machine learning techniques as discussed below.

The basic information provided to the DPC by each of the mmWave BSs is the shape of band-limited time-variant channel impulse response (CIR). When the space is free from drones, the properties of CIR do not change significantly, since most of the moving vehicles and humans are located in the bottom area (near ground). A flying drone reflects the transmitted signals thus producing additional taps that are visible in CIR of several mmWave BSs. Such cases have to be recognized by the DPC with high levels of reliability.

Machine-learning procedures are important here, since the surrounding environment is changing continuously, by potentially causing perturbations in CIR. Hence, all the biases have to be accurately examined by a comparison procedure that employs reference data patterns stored in the CDS. Taking into account the object specifics, the DPC should understand that some objects do not pose any threat and do not have to be neutralized. The result of machine learning operation aims to help interpret the data and can be used for forecasting, diagnostics, control, and validation purposes [14].

To further make the operation of Tx and Rx more intelligent, some of the antennas might be (de)activated or adjusted for the task at hand. A corresponding joint operation algorithm may reside in the DPC; however, its specific realization is heavily controller-dependent. The controller – empowered with enhanced hardware periphery – is able to mutually synchronize antennas by following the said algorithm.

To maximize the probability of drone detection as well as identification, the CDS is used. This cloud-based data storage controls an extensive amount of classified drone-specific data patterns; this reference data is then used by the DPC for the purposes of comparison. However, conventional approaches in data analysis may no longer be sufficient, and new methods for efficient analysis are required. Therefore, new interdisciplinary math techniques need to be developed, which encompass statistics, pattern recognition, and machine learning to support the analysis of data and discovery of principles hidden within this data.

E. Densification of Tx and Rx systems

Successful ADr detection is directly and strongly connected to the density of elements in the Tx and Rx system deployments: higher density generally increases the detection probability. Depending on the type of drones, their dimensions, as well as the presence or absence of payload, the scattered signal may propagate in unpredictable directions.

Produced with our ray-based modeling tool, Fig. 4 demonstrates the reflection capability of a relatively small unloaded drone (left side) and a relatively large drone carrying a square box located in its bottom part (right side). In the course of the simulations, accurate 3D CAD models of drones interacted with a single transmitter operating at 28 GHz central frequency and having 0.5 MHz of bandwidth, while multiple (about 1,000) receivers distributed in the X-Y plane collected the reflected/diffracted/scattered electromagnetic field. The displayed image was obtained via the inverse Fourier transform of the said field and has a direct relation to the RCS. The reflected power is represented by a color bar, where red color

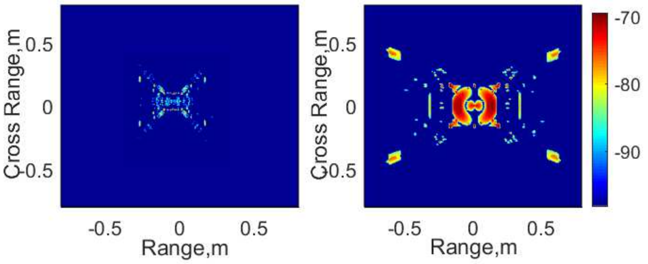

Fig. 4. Reflection capability of a small unloaded drone (left side) and a large drone carrying a box (right side).

corresponds to higher power (scattering centers) and blue color indicates lower power. As one can observe, the right plot has more red-colored areas, which highlight the scattering centers with higher power.

Accordingly, if the directions of the reflected signal are not aligned with the position of the receiving mmWave BSs, this signal may not be detected. Such areas can be observed as blue regions in Fig. 4, e.g., at the coordinates [0 0.2] in the left image and [0 0.5] in the right image. The above mentioned approach is typical for radar application and might be applied for processing of a reflection patterns. The methodology may also be extended for estimation of drone detection probability in urban deployment by adding to simulation elements of architecture (such as buildings), antenna models with properties similar to those obtained in Sec. IV C and adopted physical/postprocessing parts. In the frame of the simulation fixed number of Tx sources and varying density of mmWave BSs for different drone sizes (see Fig. 5) is considered. For each considered density of the BSs, we model up to 100 locations of the drone as well as assess the number of receivers that have acquired the scattered signal above the noise level. To this aim, Fig. 5 reports on the average number of such receivers, which have successfully detected the signal.

In summary, 5G mmWave networks become an attractive candidate technology for the intended radar system implementation, as shrinking the coverage area and densifying the BS deployment are their key inherent properties. Integrating the proposed radar functionality as described above makes drone detection more reliable and turns the 5G system into a distributed monitoring network. If required, such distributed network may additionally recognize the type of the flying object, thus reducing the probability of failure. To achieve this, it is required to take into account the RCS samples of Rx (see Fig. 5) and compare those with the data stored in the CDS. Whenever densification with the BSs is not sufficient to achieve reliable ADr detection or pathloss between the antennas remains large, additional transmitting antennas may be installed. However, such situations are unlikely as future networks move toward ultra-dense deployments.

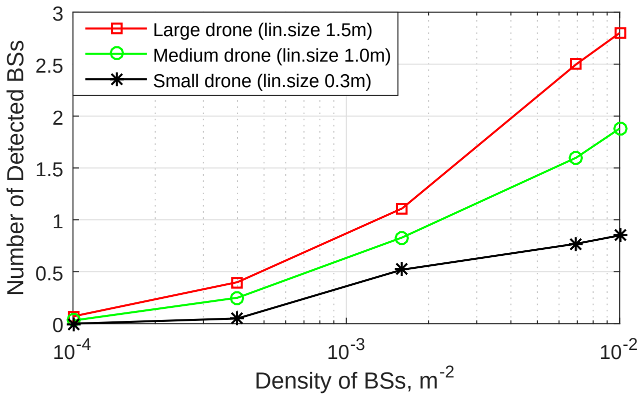

Fig. 5. Detection levels for ADr of different sizes by 5G mmWave BSs.

V. Future Challenges and Open Issues

Integration of radar functionality into 5G infrastructure gives rise to important further challenges and open research directions, which we outline in this section.

Resource management related aspects. Since radio resources of mmWave BSs remain limited, distributing these resources between communication and radar functionalities while maintaining the quality of operation for both modes on the required level becomes a highly convoluted issue. A potential solution to improve the spectrum sharing efficiency is to employ cognitive radio techniques [15]. Generally, resource management might be addressed at hardware, PHY, and MAC layers. A number of corresponding problems need to be investigated, e.g., defining the minimum technical requirements on the mmWave BS exploited as a receiving element of the multistatic radar system. Accordingly, we distinguish the cases when the system (i) supports switching between radar and communication modes and (ii) supports simultaneous operation of radar and communication modes. Detailed consideration of these cases calls for development of new algorithms for resource allocation and sharing across the two operating modes.

NLoS radar operation. As mentioned above, dense deployment of mmWave BSs is required for both the communication and radar modes. However, some of the BSs might be deactivated for certain reasons, which in turn reduces the levels of drone detection reliability. In addition, because of urban scenario specifics, the nearest BSs may be located in the non-line-of-sight (NLoS) conditions with respect to the deactivated BS(s). To maintain the detection probability reasonably high, the NLoS BSs may also participate in the considered detection procedure.

Noise mitigation techniques. Today, conventional urban deployments are not typical for radar applications, which are primarily optimized to operate in open-space regions. Urban scenarios have a considerable number of noise sources, which may lead to faulty detection. This negative effect can be mitigated by utilizing advanced machine learning algorithms for recognizing and classifying the noise sources together with their location, based on the antenna directivity. Further, such data may be taken into account when the drone detection procedure is triggered.

Scanning procedure considerations. The procedure of scanning the upper hemisphere is central for the described system, since it provides information on the ADr location.

However, properties of the corresponding steering mechanism may raise further questions, such as the optimal selection of the interference beam steering regime in terms of the core radar metrics. In addition, being a source of considerable disruption, background noise impacts the detection capabilities during the beam movement; the means for reducing this negative effect require further research.

Big data management. More investigation might also be demanded by multi-step detection techniques that employ complementary detection technologies to verify the radar data and reduce the false detection probability. These technologies include infrared and visible detectors, acoustic arrays, time-of-flight equipment, and electromagnetic detectors. Employing information from multiple BSs as well as such complementary sensors, leads to a challenge of big data management. Despite the fact that the described task is novel in this context, in the last decade computers have provided with inexpensive capabilities to collect and store big data.

Network planning aspects. It is well known that network planning is central to achieve high-quality communication. The same holds true for built-in radar systems, which should also be deployed by taking into account a number of parameters. The planning tasks may include evaluation of the minimum number of mmWave BSs required in a given locality to ensure the detection of drones of a particular size with a certain probability. Further, increasing the quality of detectable data might be necessary to improve the drone recognition properties. Hence, the problem of determining the type of a drone arises based on the scattering properties. Finally, since the transmitting system may be omnidirectional, the challenge of interference mitigation despite the densification of mmWave BSs may play an important role.

VI. MAIN CONCLUSIONS

Utilization of 5G mmWave BSs as radars for detecting unauthorized drones is a new direction in research. By employing our in-house ray based modeler as well as building on several theories, we contributed our vision of the corresponding system design with the drone detection capability that relies on 5G mmWave infrastructure. In particular, we observed that the high bandwidth (up to 2 GHz) of mmWave band offers a number of benefits for early detection of rule-violating ADr. This is because we expect that small-sized drones will prevail as the main violators of air traffic rules in urban scenarios as well as may serve as instruments of unlawful acts from the side of their operator.

We demonstrated that the utilization of a high-gain mmWave antenna with beamforming capabilities has the potential to provide better accuracy for drone detection purposes, since it might interfere less with the signals coming from the low-gain directions. Moreover, reuse of the phased antenna arrays with beamsteering properties brings benefits in terms of more intelligent assessment of the threat level. However, due to the added complexity, not every mmWave BS can support such an operation. In particular, mmWave MIMO BSs with digital beamforming (and possibly hybrid beamforming) become preferred candidates for this role, as they can deliver simultaneous operation of radar and communication modes. Switching between these modes might be resource demanding, thus decreasing performance efficiency in both modes.

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