Low Altitude Target Detection Technology Based on 5G Base Station

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Abstract. With the rising of the civil UAV (Unmanned Aerial Vehicle) industry and the opening of low-altitude airspace, UAVs are frequently used for privacy snooping, terrorist attacks and similar activities, which greatly harm people's safety and social security. However, in the complex urban environments, traditional low-altitude target detection methods are difficult to effectively detect small low-altitude targets which have small size and low speed. With the advent of 5G, intensive networking of 5G base station makes 5G signal is the most abundant resources of electromagnetic in the city, using 5G as external illuminator signal can not only realize the effective detection of low altitude small target, also save the cost, reduce the impact on the urban electromagnetic environment such as the radar, promoted the radar communication integration. Based on the above research background, this paper mainly studied the low altitude target detection scheme based on 5G base stations which is applicable for urban environment. This scheme using 5G base stations as radar transmitters, 5G signal as radiation source, set up the receiver receives the forward scattering signals from the target in order to achieve low altitude target detection and imaging. This paper systematically discusses the feasibility and advantages of 5G signal used as radar radiation signal, studies its radar performance, and the simulation proves its superior speed resolution and range resolution. It provides theoretical basis and support for the application of low-altitude airspace accurate detection and so on, and pushes forward the integration process of radar communication.

Keywords: Low altitude target detection · 5G · Forward scattering · Bistatic radar

1 Introduction

Low-altitude targets mainly refer to "low-altitude, slow-moving and small-sized flying targets" which common feature is that it is difficult to detect when reflected on radar. Therefore, UAVs are often used to spy on intelligence and privacy, causing public

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security hazards. For example, some lawless elements use UAVs to peek at some large-scale activities or carry out negative publicity, and even use UAVs to carry out explosions and other terrorist attacks [1].

Recent years, with the rapid rise of UAV high-tech companies such as “DJI” and the further opening of low-altitude airspace, the civil UAV market has further expanded. So how to achieve the effective detection and control of low-altitude small targets has become an urgent security problem.

Low-altitude target detection technology refers to the technology that can effectively detect and track all kinds of low-altitude targets. At present, there are three main technical means: acoustic detection, photoelectric detection and radar detection [2]. The range of acoustic detection is limited to a relatively close range. Optical schemes have high recognition accuracy, but they are easily affected by weather. Traditional radar detection is difficult to separate the echo of low-altitude target from strong ground or object clutter and strong noise, which requires strong signal processing capability. Therefore, it is extremely necessary to find a new system scheme which is suitable for urban low-altitude target detection.

Compared with the traditional monostatic radar, the bistatic radar adopts the design that the receiver and transmitter are separated, and mainly utilizes the forward scattering characteristics of electromagnetic waves [3, 4]. When the target is in the forward scattering region of bistatic radar, its RCS (Radar Cross-Section) can be increased by more than 10db [3], the echo signal will be greatly enhanced. Compared with the traditional monostatic radar, bistatic radar is more suitable for detecting low-altitude small targets with relatively small RCS.

However, it is difficult to implement the traditional bistatic radar in cities for the following reasons:

1. The large-scale setting of high-power radar transmitter in the city will cause serious interference to the original electromagnetic environment of the city.
2. The city is full of high-rise buildings and multipath effect will greatly affect the radar target echo signal and it is difficult to carry out subsequent signal processing.
3. Theoretically, covering the airspace of a standard-sized city requires hundreds of radar receivers and transmitters, but this is only for the purpose of achieving the monitoring of low-altitude small targets or UAVs, and the cost is not proportional to the investment.

But, if the existing communication signal of the city is used as the radar radiation source, electromagnetic pollution can not only be effectively avoided, but also the cost can be save. In the 4G era, it is difficult for the bandwidth and wavelength of communication signals to reach the accuracy and resolution of detecting low-altitude target, but with the development of 5G, 5G signals have wider bandwidth, denser networking and higher carrier frequency, which greatly optimizes the radar detection resolution, detection accuracy and data fusion of bistatic radar based on 5G base stations. It is a good solution for urban low-altitude target detection.

In this paper, a low-altitude target detection system based on 5G base station is proposed which consists of a radar network composed of several 5G base stations and detection radar receivers. Using 5G signals as radar radiation sources, when the target crosses the baseline formed by 5G base stations and receivers, the target will radiate forward scattered waves and be received by the radar receiver. When the target passes the baseline, the intensity of forward scattered waves is theoretically more than 10dB greater than backward reflected waves, which can effectively detect low-altitude small targets (Fig. 1).

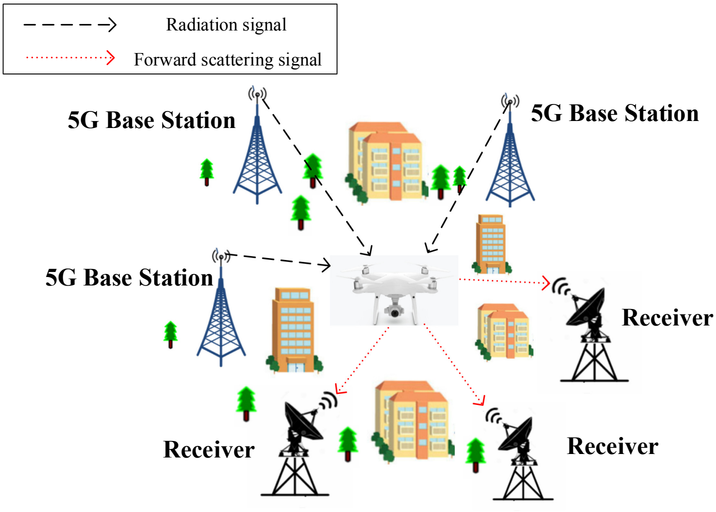

Fig. 1. Low altitude target detection system based on 5G base station

2 Performance of 5G Signal Radar

2.1 Advantages of Communication Radar Integration

The use of 5G signal as the radar radiation source can rely on the rich electromagnetic resources in the urban environment, and make rational use of multiple base stations completes dense networking and multi-angle detection.

In different environments, different communication signals are converted and data fusion is carried out to meet the requirements of width and accuracy for low-altitude target detection, improve the detection performance, and make up for the shortcomings of traditional low-altitude target detection system, such as small detection range and low accuracy. At the same time, the system has the potential of anti-stealth, anti-interference ability and so on.

2.2 Millimeter Wave

The band width of 4G signal is about 20 MHz. According to 3GPP protocol, the two main frequency bands used by 5GNR are FR1 (450 MHz–6 GHz) and FR2 (24.25 GHz–52.6 GHz), and the electromagnetic wave in FR2 is millimeter wave [5]. For FR1 band, the channel width can be up to 100 MHz, while the millimeter band can be up to 400 MHz. According to the theory of digital communication system, the bandwidth is positively correlated with the transmitted signal rate. Combined with other technologies of 5G, the transmission speed of 5G signal will increase by more than 100 times, which greatly speeds up the transmission speed of data, shortens the response time, reduces the data delay, and solves signal synchronization problem of transmitting and receiving base in some traditional bistatic radars [6].

Influence of Millimeter Wave on Range Resolution. Because the wavelength of millimeter wave is less than 10mm, the antenna length will be greatly shortened and the size of the base station will become smaller. Therefore, the beam of millimeter wave is narrower than the signal in microwave band, which means that it has better directivity, higher resolution and better positioning accuracy, and can distinguish small targets with closer distance and observe more details [7].

The minimum distance interval between two targets that can be resolved by bistatic radar is called distance resolution [8, 9]:

$$\Delta R = \frac{\mathrm{c}}{2B\cos(\beta/2)} \tag{1}$$

Where B is signal bandwidth, β means bistatic angle, and c is the speed of light.

According to the above formula, the range resolution of bistatic radar is negatively correlated with bistatic angle and signal bandwidth. Through simulating the range resolution by formula (1) we can get Fig. 2. It can be observed from the figure that with the increase of bistatic angle, its range resolution becomes worse. When the bistatic angle is 175 °, that is, when it is about to cross the baseline, its range resolution is about 170 m with the bandwidth is 20 MHz of 4G signal and 8 m with the bandwidth rises to 400 MHz. Under the same bistatic angle, the range resolution is improved by 20 times, which greatly increases the feasibility of distinguishing between two objects that are closer.

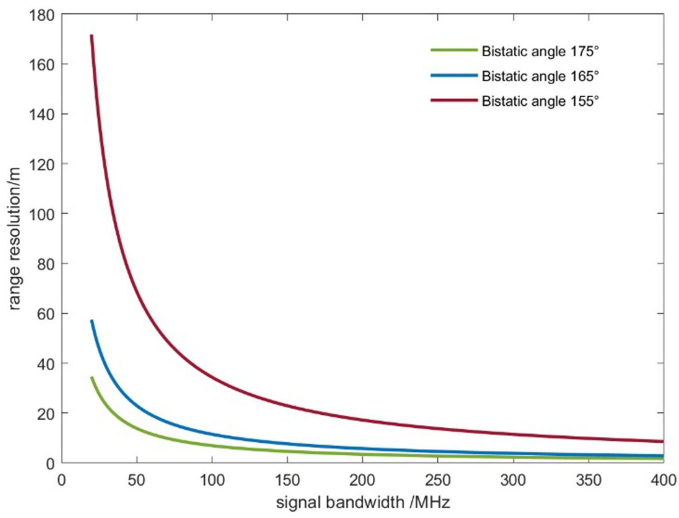

Fig. 2. The relationship between range resolution and signal bandwidth at different bibase angles

When the bistatic angle is a fixed value, with the increase of signal bandwidth, the range resolution is in a sudden drop state from 20 MHz to 100 MHz, and the range resolution is in a low value from 200 MHz to 400 Hz.When the bistatic angle becomes 155 °, the range resolution is as low as 1.7m (when the signal bandwidth is 400MHz). This greatly improves the detection performance of its radar, and makes the 5G signal have more outstanding advantages than other external radiation source signals.

Influence of Millimeter Wave on Velocity Resolution. Velocity resolution refers to the ability of radar to distinguish two moving targets with similar velocities.

Under the condition of fixed bistatic angle, when the target crosses the baseline in the direction perpendicular to the baseline ($\delta = 0^{\circ}$), the velocity resolution of the target is as follows [8, 9]:

$$\Delta V = \frac{c}{2f_0 T\cos(\beta/2)} \tag{2}$$

It can be seen from the above formula that the velocity resolution of radar is mainly related to the signal frequency (f_0) and coherent integration time (T). It is known that the frequency of 4G signal is 1.8 GHz–2.6 GHz, while the highest frequency of 5G signal can reach 52.6 GHz (FR2) at present. Figure 4 shows how the velocity resolution of the radar varies with the signal frequency at different coherent accumulation times (Fig. 3).

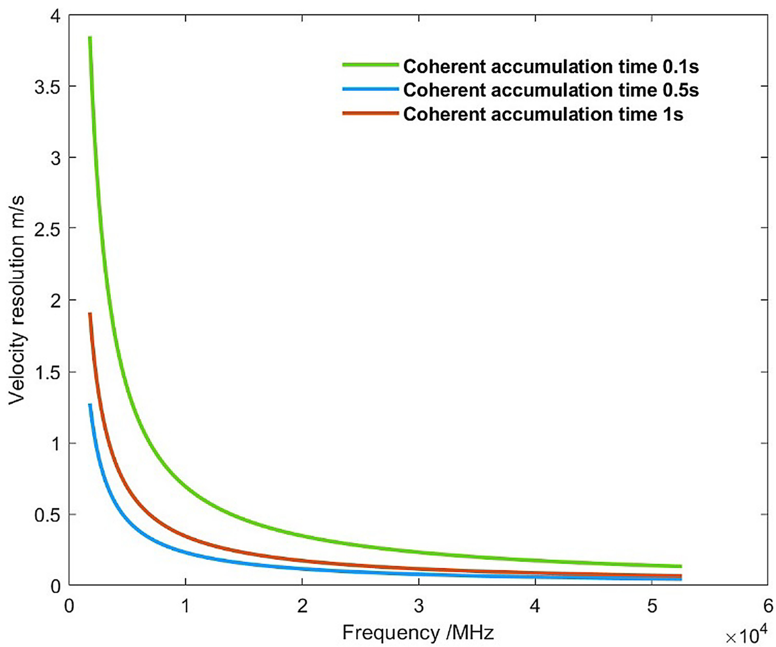

Fig. 3. Relationship between velocity resolution and carrier frequency and accumulation time

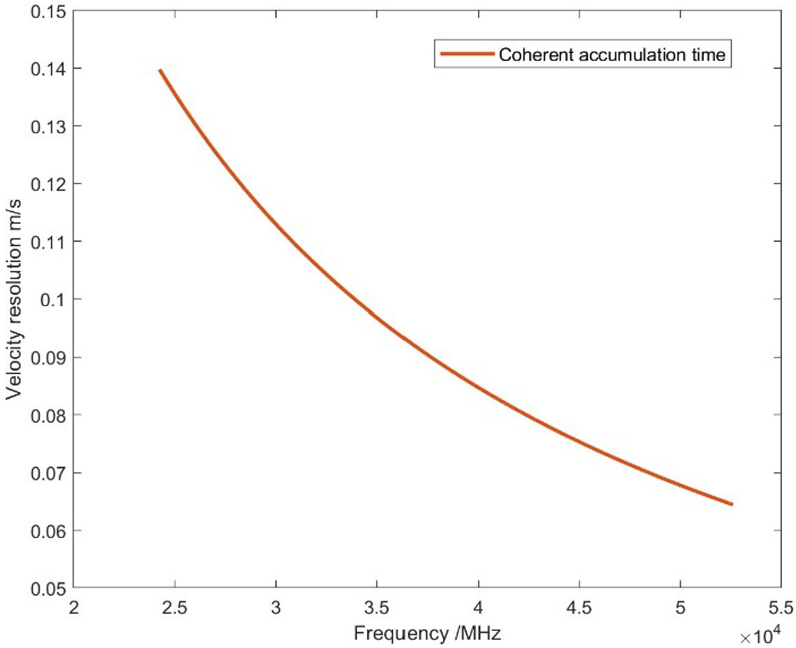

Fig. 4. Velocity resolution when coherent accumulation time is 1s

It can be seen from Fig. 4. That for a fixed coherent accumulation time, the velocity resolution of the radar decreases with the increase of carrier frequency and is in a state of sharp decline at 0–10 GHz. Under the condition of constant carrier frequency, the longer the coherent accumulation time, the lower the velocity resolution. For millimeter wave, the velocity resolution of 0.1 s or 1 s coherent time is quite different, while the velocity resolution of 0.5 s and 1 s coherent time has small differences.

Figure 5 mainly shows the velocity resolution in FR2 (24.25 GHz–52.6 GHz) when the coherence time is 1s. In this state, the velocity resolution is below 0.14 m/s. Although it is an ideal assumption, it still shows the powerful velocity resolution of 5G mm band signal.

2.3 Beamforming

The concept of beamforming originated from phased array radar in radar field. Phased array radar mainly relies on several antenna units assembled together. By controlling the radiation direction of different units, the radiation waves of all units are combined together to form an effective beam main lobe and radiate to a specific direction [6].

Using the principle of phased array radar for reference, beamforming is to replace the original single antenna with an antenna array composed of multiple antennas, so that it can generate radiation signals with narrow beams pointing in a specific direction. The technology allows most of the power to be directed in a specific direction rather than being radiated in a 360-degree direction, wasting most of the energy in free space.

Therefore, beamforming makes the radiation power reaching the designated target higher, and makes the target which with smaller RCS receive greater radiation power than the original one, thus improving the detection ability of 5G signal to small targets. At the same time, because the beam radiates in the specified direction, the multipath effect is weakened, the interference is reduced, and the probability of finding small targets is also improved. This application also reduces the beam width, which brings higher resolution and lower power consumption to radar target detection.

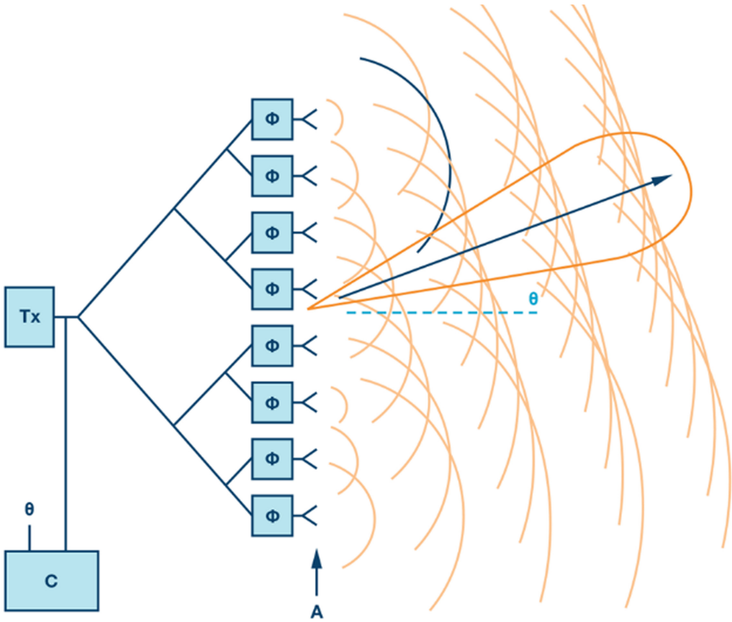

Fig. 5. Schematic diagram of phased array radar

2.4 Massive MIMO

Massive MIMO refers to multi-channel input and output, which can establish contact with multiple users on the same channel, receive and send data at the same time. In the 4G era, the MIMO technology used usually uses 2 or 4 antennas, but in the 5G era, the number of antennas is theoretically unlimited, and the communication capacity is also unlimited. The combination of Massive MIMO and beamforming makes the 5G signal have the characteristics of beamspace multiplexing, which greatly improves the spectral efficiency. The scanning rate of 5G signal as radar signal is also improved, and the target can be found faster without affecting its communication performance.

In 4G era, the antennas are long and few in number, and 5G signals work in millimeter wave band with short wavelength and short antenna length, so more antennas can be integrated in the same base station at the same time to form Massive MIMO. With the increase of the number of antennas, the gain also increases, and the forward scattering power of the target received by the receiver is also larger, which can better detect low-altitude small targets.

3 Conclusion and Prospect

3.1 Conclusion

This paper mainly discusses the low-altitude target detection technology based on 5G base station, and proposes a new urban low-altitude target detection scheme. 5G base station and radar transmitter will be combined into one, and 5G signal will be used as radar transmitting signal. When the target aircraft passes through the baseline between 5G base station and radar receiver, the receiver will receive the forward scattering wave of the target, thus realizing the detection of low-altitude small targets.

This paper demonstrates the feasibility of 5G signal as radar detection signal, verifies the good radar performance of 5G signal and analyzes the advantage of communication signal as radar radiation signal. Among them, Millimeter wave reduces the transmission delay and solves the problem of partial synchronization. The narrower beam width of millimeter wave makes the radiated signal have better directivity and positioning accuracy. The application of beamforming reduces unnecessary power loss, and directional radiation reduces the influence of multipath effect. Massive MIMO enables 5G signals to have the characteristics of beam multiplexing, which greatly improves the spectrum efficiency and scanning rate, and reduces the influence of radar on the communication performance of base stations. At the same time, the radar performance index of 5G signal is simulated and analyzed, which verifies that 5G signal has better velocity resolution and range resolution.

3.2 Prospect

In this paper, a new low-altitude target detection system based on 5G base station is proposed, and the radar performance of 5G signal is explored and studied, and some results are obtained. However, there is still a long way to go before the actual commercial use of the system. Many details can be optimized and many functions can be realized:

1. Although the radar forward scattered signal can well detect low-altitude small targets by increasing the RCS of the target, compared with the backward reflected signal of the target, part of the effective information of target movement is still missed. Therefore, under the premise of urban 5G dense network, the receiver may receive backward reflection and forward scattered signals transmitted to the target and reflected to the receiver by different base stations at the same time. If a data fusion center is established to fuse the two signals received by the receiver, the motion state of the low-altitude target can be obtained more comprehensively, and the future motion direction can be predicted with higher accuracy.
2. The height difference and midline information of the aircraft can be obtained by analyzing the target holographic signal. Different aircraft have different altitude difference and midline information, which can be combined with machine learning to take the altitude difference and midline information as the classification standard, so that the receiver can directly predict the type of aircraft after receiving the forward signal of the target, so as to achieve early warning. Depending on the dense

network of 5G base station, it can explore the radar positioning scheme of multi-external radiation sources and the tracking detection method of the start and maintenance of multi-radar target track. Once the position of the aircraft target is determined, the movement trajectory of the aircraft can be tracked continuously to realize real-time monitoring.

The research and development of low-altitude target detection technology based on 5G base station accelerates the realization of radar communication integration and improves the integration capability of communication network. At the same time, by using the characteristics of low delay and high speed of 5G network, intelligence can be reported quickly, thus make a quick response and create a fast, efficient and low-cost low-altitude target detection solution. It is a realistic and inevitable choice to complete low-altitude target detection by means of a communication network with high coverage and dense networking in cities, with unlimited application potential.

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