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THE ROLE OF DRONES AND INTELLIGENT REFLECTIVE SURFACES IN BROADBAND TRANSMISSION OVER 5G AND B5G MOBILE NETWORKS IN SMART CITIES

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Abstract

This paper presents innovative technologies that should enable broadband data transmission necessary for the implementation of new services and functions in smart cities. The technologies that we expect to be applied in 5G and B5G (6G) mobile networks have been analysed in particular. Given that these networks imply a significantly higher density of base stations, it is expected that drones will be largely used for their implementation as aerial base stations (ABS). Drones can be used as carriers of appropriate antenna systems, which by their nature are complex active devices and have significant energy consumption. Another variant is to install the so-called intelligent reflective surfaces (IRS), by their nature passive devices and therefore more energy efficient. The principles of functioning, advantages and disadvantages of the IRSs are presented in more details.

Keywords: *smart city, drones, Internet of Drones (IoD), B5G, 6G, intelligent reflecting surface (IRS)*

Introduction

Smart cities are an urban development concept that focuses on the integration of information and communication technologies (ICT) in order to improve the efficiency, sustainability and quality of life of citizens [1]. These cities use ICT infrastructure and sensors to collect data from various sources, such as public transport, energy networks, weather conditions and waste management. Smart cities use this data to better manage city resources and services. For example, they can be used to optimize traffic, reduce energy consumption, improve

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public safety and provide better services to citizens. They can also be applied to improve air quality, water management, smart parking and more [2].

Smart cities also promote citizen involvement and interaction between citizens and city administration. This is achieved through digital platforms and applications that allow citizens to provide feedback, report problems and participate in decision-making processes. This concept aims to create more sustainable, efficient and innovative cities that can improve the quality of life of its citizens. Smart cities have several advantages over traditional cities. Some of key benefits are:

- Resource efficiency: Smart cities use information and communication technologies (ICT) to manage resources more efficiently. For example, they can use sensors to monitor energy and water consumption, optimize traffic flows to reduce congestion and fuel consumption, or manage lighting and waste more efficiently. This leads to a reduction in the consumption of resources and costs, as well as a reduction in the negative impact on the environment.
- Improved traffic efficiency: Smart cities use technology to improve traffic flows and reduce congestion. For example, they can use sensors and traffic data to provide information to drivers about optimal routes, available parking spaces or available transportation. This leads to reduced travel times, less congestion and less emissions.
- Better public safety: Smart cities use technology to improve public safety systems.
- For example, they may use video surveillance, sound sensors or data analysis to identify potential threats or irregularities. This helps to respond more quickly to incidents, reduce crime and increase the sense of security among citizens.
- Better services to citizens: Smart cities use digital platforms and applications to improve communication and provide better services to citizens. For example, citizens can use mobile applications to report problems in the city, access information about city events, or use electronic services to pay bills or obtain permits. This makes it easier for citizens to interact with city administrations, get faster answers and participate in decision-making processes.

Information and Communication Technology (ICT) forms the basis of a smart city. It includes physical infrastructure such as high-speed Internet connection, data centers, communication networks and sensors that collect data from various sources in the city. Smart cities rely on data collection through sensors, devices and systems deployed throughout the urban environment. This data is processed, analyzed and transformed into useful information, enabling evidence-based decision-making and efficient resource management. The broadband data transmission is necessary for the implementation of these new services. It is expected that 5G and B5G (6G) will be widely used for this purpose.

New Technologies for Smart Cities

Different technologies are often used in smart cities to improve efficiency, sustainability and quality of life for citizens. Some of the key technologies expected to be the basis for the development of smart cities are [1]:

- Internet of Things (IoT): IoT is a technology that enables the connection and exchange of data between physical devices and systems via the Internet. In smart

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cities, sensors and devices are used to collect data on traffic, air quality, waste management, energy efficiency and other aspects of city life.

- Networks and communications: Advanced communication networks, such as high-speed broadband networks (such as 5G, B5G) and wireless networks, enable the connection of various devices and systems in a smart city. These networks enable fast and reliable data exchange between sensors, devices, infrastructure and central control systems.
- Artificial Intelligence (Artificial Intelligence - AI): Artificial intelligence is used to analyze large amounts of data collected in a smart city. AI algorithms are applied to predict traffic jams, optimize public transport routes, manage the energy grid, monitor security and process data for more efficient decision-making.
- Big data and analytics: Large amounts of data (big data) collected from various sources are analyzed in order to obtain useful information about city processes. Data analytics help identify patterns, uncover trends, predict citizen needs, and optimize city resources and services.
- Smart Energy Grid: The Smart Grid uses technologies and communication systems to enable efficient management of electricity production, distribution and consumption. This technology enables better monitoring and management of energy consumption, integration of renewable energy sources and reduction of network losses.

The Role of Drones in Smart City Infrastructure Integration

Drones (unmanned aerial vehicles) will have a special role in smart cities, and in particular the Internet of Drones (IoD) technology additionally contributes to their integration and connection within smart city infrastructures [3]. Some of the ways drones and IoD are contributing to connectivity in smart cities are:

- Inspection and monitoring of infrastructure: Drones are used to inspect and monitor infrastructure in the city, such as bridges, buildings, roads, power grids and water pipes. Drones can quickly and efficiently collect visual data and high-resolution footage, enabling the rapid identification of damage, faults or problems that require intervention.
- Traffic and Transportation: Drones can be used to monitor traffic in real time, identify congestion and road irregularities.
- Security and surveillance: Drones can be used to monitor and secure public spaces, parks, stadiums and other city facilities. The ability to fly drones makes it possible to cover large areas and quickly identify potential security threats.
- Air quality and environmental monitoring: Drones can be equipped with sensors to measure air quality, noise, temperature and other environmental factors.
- Emergencies and Response: Drones can quickly arrive at the scene of an accident or emergency and provide real-time information about the situation.
- Monitoring of city works: Drones are used to monitor and document city works, such as the construction, renovation and maintenance of roads, buildings and parks.

IoD technology contributes to connecting drones in smart cities by enabling their integration into existing networks and systems. This includes exchanging data between drones, central

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control systems and other smart devices in the city. IoD enables the coordination and management of drone flight, data analysis and automation of certain tasks, which contributes to the efficiency and reliability of drones in the context of smart cities. The combination of flying height, precise positioning, drone network, dynamic adjustment and emergency network setup allows drones to provide better network coverage in dense urban areas. This technology can improve signal quality, reduce interruptions, increase network capacity and enable reliable connectivity in urban areas where traditional base stations may be limited by obstacles.

IoD technology can also be used to support 5G and B5G data transmission in smart cities by expanding network coverage and capacity, rapid network setup in emergency situations, forming a network for connecting drones, improving network management and network maintenance [4]. This integration of drones into the network infrastructure of smart cities can contribute to the faster spread and improvement of wireless communications in urban environments.

Broadband Transmission Over 5G and B5G Networks

Broadband transmission, 5G (fifth generation mobile network) and B5G (Beyond 5G) are of great importance for future smart city services for several reasons. Broadband transmission, 5G and B5G technologies enable extremely high data transfer rates [5]. It is vital for smart cities as it supports the transfer of large amounts of data in real time. Fast transmission speeds enable advanced services such as high-quality video streaming, virtual and augmented reality, smart cameras and IoT (Internet of Things) devices that require high bandwidth. 5G and B5G technologies are characterized by extremely low latency, which is the time from sending a request to receiving a response. This is crucial for smart cities as it supports applications with high demands for real-time responsiveness. For example, autonomous vehicles, smart traffic management, emergency systems and industrial IoT require minimum latency to ensure fast and reliable communication. 5G and B5G networks can support a huge number of connected devices. This is crucial for smart cities as IoT devices are expected to be ubiquitous, connecting all aspects of the city, from infrastructure, traffic and energy to public safety and waste management. Greater device connectivity enables data exchange and communication between different systems, leading to more efficient and intelligent city management.

Smart cities generate large amounts of data from various sources, including sensors, cameras, smart devices and other IoT devices. 5G and B5G technologies enable fast and reliable processing of that data in real time. It enables cities to apply advanced data analytics to optimize traffic, energy efficiency, waste management, public safety and other aspects of city life. 5G and B5G technologies enable the development of new advanced technologies and services that will shape the smart cities of the future. These include autonomous vehicles, smart grids, smart infrastructure, smart homes, virtual and augmented reality, robotics and other innovative technologies. These technologies will improve efficiency, sustainability, comfort and quality of life in smart cities.

In Table 1. the evolution of mobile wireless communications is shown using the most important technological characteristics from 1G to the recently proposed 6G networks.

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Table 1: Evolution of mobile communications

Network / Features	1G	2G	3G	4G	5G	6G
Start	1970	1980	1998	2000	2010	2020
Deployment	1984	1999	2001	2010	2019	2030
Technology	AMPS, NMT, TACS	GSM, GPRS, EDGE	WCDMA, UMTS	LTE, WiMAX	MIMO, mm Waves	THz communications, VLC
Frequency	30 KHz	1.8 GHz	1.6-2 GHz	2-8 GHz	3-30 GHz	95 GHz-3 THz
Multiplexing	FDMA	TDMA/CDMA	CDMA	OFDMA	OFDM	OFDM
Switching	Circuit	Circuit, packet	Packet	All packet	All packet	All packet
Core network	PSTN	PSTN	Packet Network	Internet	Internet	Internet
Primary services(in addition to previous generations)	Voice calls	International roaming, voice calls, SMS, MMS, WAP, WWW, and emails	Video conferencing, GPS	Mobile web access, IP telephony, 3D videos, HD mobile TV	Machine vision, connected cars, snart homes, AR	Tactile and haptic internet, connected autonomous systems, holographic society
Peak data rate	NA	50 Kbps(GPRS), 1 Mbps (EDGE)	21 Mbps	100 Mb/s	20 GB/s	≥1 Tb/s
Mobility support	NA	NA	NA	350 km/h	500 km/h	≥1000 km/h
Latency	NA	300 ms	100 ms	10 ms	1 ms	10-100 μs

Some additional benefits of 5G and B5G technologies, such as higher energy efficiency, better scalability, multiple connectivity, better network management, and greater security and privacy, contribute to the development of intelligent and sustainable cities. These technologies enable cities to provide advanced services, optimize resources and improve the quality of life of their citizens. In short, broadband, 5G and B5G technologies are key to the development of smart cities. They enable high data transfer speeds, low latency, greater connectivity of devices, mass data analytics in real time and support the development of advanced technologies and services. These technologies will improve the efficiency, sustainability and quality of life in the smart cities of the future.

Intelligent Reflective Surfaces for B5G Networks

One of the most important new technologies foreseen for smart cities are the so-called Intelligent reflective surfaces – IRS [6]. Intelligent reflective surfaces have a potential role in B5G networks, as a technology that can improve network coverage, capacity and efficiency. These surfaces are also called reflective metasurfaces or intelligent surfaces.

The physical principles underlying intelligent reflective surfaces include wave propagation, reflection, and interference. Wireless communication relies on the transmission of electromagnetic waves. These waves propagate through air or other media and carry

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information. In the case of 6G networks, these waves typically operate in the millimeter wavelength and terahertz range, allowing for higher data throughput and transmission speed. When an electromagnetic wave encounters a surface, such as an intelligent reflective surface, it can be reflected. Ordinary surfaces, such as walls or buildings, reflect the waves in a diffuse manner, scattering them in different directions. In contrast, intelligent reflective surfaces can manipulate wave reflection in a controlled and precise manner. Individual elements or units that make up an intelligent reflective surface can dynamically adjust their electromagnetic properties, such as phase or amplitude. By changing these properties, the surface can control the direction, phase and amplitude of the reflected waves. Intelligent reflective surfaces aim to optimize the propagation of wireless signals. They achieve this by intelligently adjusting the reflection properties of the elements to direct the waves to the desired locations or receivers. By manipulating the reflected waves, the surface can improve signal strength, extend coverage, increase capacity and reduce interference. Intelligent reflective surfaces can also be used to manage interference in wireless networks. They can adjust the reflected waves to remove or reduce unwanted interference, thereby improving signal quality and overall network performance. By placing intelligent reflective surfaces in strategic positions, 6G networks aim to achieve more efficient and reliable wireless communication. These surfaces can help overcome challenges such as signal loss, signal blocking, and multiple bounce by shaping and optimizing the propagation environment to improve signal strength and quality at the receiver.

IRS can contribute to B5G networks in smart cities in the different ways. Intelligent reflective surfaces can be used to direct and focus electromagnetic waves. This means that they can be placed in strategic locations in the city to improve network coverage in certain areas that are otherwise poorly covered or have poor signal quality. In this way, reflective surfaces can help eliminate "dead zones" and provide reliable connectivity in all parts of a smart city. They can be used to increase network capacity by placing reflective elements in optimal locations to increase signal speed and throughput. These surfaces can direct signals towards points where a higher network load is required, such as public places, stadiums, squares or business zones. This improves network capacity and provides a better experience for users in those areas. They also can be used to reduce interference between different cells in a network. For example, reflective surfaces can be placed between adjacent base stations to reduce interference and increase network efficiency. This is important in densely populated urban areas where there are many overlapping cells.

Intelligent reflective surfaces can be used to optimize the energy efficiency of the network. For example, reflective surfaces can direct the signal to desired areas, reducing the need for a strong signal that would otherwise be required. This reduces the energy consumption of base stations and improves the energy efficiency of the network. They can be programmed and adjusted according to the needs of the network. They can be optimized for different frequencies, bandwidths and signal propagation conditions. This enables the flexibility and adaptability of the smart city network to meet the changing needs of users and applications.

When IoD is used as a carrier of IRS for Aerial Base Stations, some interesting possibilities can be realized [7]. Aerial Base Stations (ABS) are drones used as mobile base stations to provide wireless connectivity. The integration of IRS on ABSs allows for improved

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connectivity by allowing drones to adjust the reflective properties of the surface to direct or amplify wireless signals to specific areas or users. ABSs with IRS can be used to extend the coverage of wireless networks. Drones with IRS can be deployed in strategic locations to bridge coverage gaps or provide temporary infrastructure for situations where communications need to be established urgently. Through the use of IRS, ABSs can dynamically manage network capacity. Based on information about network load or data traffic, ABSs can adjust reflective properties to optimize quality of service, balance the load, or provide priority connections where needed most. IRS on ABSs can be used to reduce interference between base stations in dense urban areas. A reflective surface can be used to direct or block signals to reduce mutual interference between ABSs and improve wireless communication quality. Integrating IRS on ABSs can provide additional layers of security and privacy. A reflective surface can be used to mask or hide signals from unauthorized access or protect communications from eavesdropping.

Closely related to IRS is massive MIMO (Multiple Input Multiple Output) technology [8]. These two technologies are used in wireless communications, but they have different functionalities and applications. As already said, reflective surfaces of the IRS can be placed on walls, surfaces or devices, such as drones, to direct signals towards specific users or areas. On the other hand, massive MIMO is a technology that uses a large number of antennas on base stations to simultaneously communicate with multiple users at the same time. This technology enables increasing capacity, improving performance and reducing interference in wireless networks. Massive MIMO base stations can have dozens or even hundreds of antennas capable of processing and transmitting signals on parallel paths to multiple users. IRS and massive MIMO can be combined to achieve even better performance of wireless networks. IRS can be used in addition to base stations equipped with massive MIMO technology. IRS reflective surfaces can be placed near base stations to improve coverage and signal directionality to users. Also, IRS can help reduce interference and increase capacity by reflecting signals towards specific users or areas. The joint use of IRS and massive MIMO can have a synergistic effect and bring additional advantages in the performance, capacity and coverage of wireless networks. These technologies represent promising research areas in the development of future generations of wireless communications such as 5G and B5G.

The application of intelligent reflective surfaces (IRS) brings numerous advantages, but there are also several open problems related to their application. Some such problems are:

- Management Complexity: Effectively managing a large number of IRSs can be challenging. It is necessary to develop sophisticated algorithms for the management, scheduling and optimization of IRSs in real time. This includes monitoring changes in the environment as well as coordinating between different IRSs to ensure optimal network coverage and capacity.
- Need for precise positioning: Effective use of IRSs requires precise positioning to achieve the desired directivity and signal gain. Precise positioning of drones with IRS can be challenging, especially in dynamic environments with lots of movement.
- Interference and coordination: When a large number of IRSs are used in the same area, interference between the reflected signals can occur. Also, it is necessary to

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ensure coordination between IRSs in order to avoid conflicts and ensure optimal `signal delivery.

- Energy Efficiency: IRSs require power to operate. It is necessary to find ways to efficiently manage the energy consumption of IRSs in order to extend the battery life of drones or other platforms on which they are installed.
- Security and Privacy: Using IRS can present security and privacy challenges. There is a risk of unauthorized access and manipulation of IRS, which may affect the integrity and confidentiality of communication networks.

It is important to note that these problems are currently an area of active research and development. As IRS technology continues to develop, many of these challenges are expected to be overcome through innovation and advancements in wireless communications and drones. These are just some of the possibilities of using IoD, IRS in the context of Aerial Base Stations. Advances in drone technology, wireless networks, and reflective materials are paving the way for innovation in this area and can bring significant benefits to the provision of communication services in a variety of environments.

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