ISSN No:-2456-2165

A Comprehensive Multi-Taxonomy of Wireless Communication Protocols for Adaptive Video Streaming in Drones

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Abstract:- Wireless communication protocols play a crucial role in enabling adaptive video streaming for drones. This paper provides two taxonomies that categorize the commonly used wireless communication protocols in this context. The first taxonomy emphasizes HTTP-based adaptive streaming protocols, including Dynamic Adaptive Streaming over HTTP (DASH) and HTTP Live Streaming (HLS), along with real-time streaming protocols such as Real-Time Transport Protocol (RTP) and Real-Time Messaging Protocol (RTMP). It also covers transport protocols like User Datagram Protocol (UDP) and Transmission Control Protocol (TCP), as well as wireless standards like IEEE 802.11 Wi-Fi protocols and 4G LTE/5G NR. The second taxonomy expands on the first by introducing additional components, including cellular network protocols, Wi-Fi protocols, satellite communication protocols, point-to-point wireless protocols, mesh networking protocols, and hybrid communication approaches. These taxonomies offer a comprehensive understanding of the wireless communication protocols used by drones for adaptive video streaming, enabling researchers, developers, and practitioners to make informed decisions regarding protocol selection and optimization. By considering network conditions, coverage requirements, and application context, these taxonomies provide insights into building robust and efficient wireless connections for adaptive video streaming in drone applications.

Keywords:- *Wireless; Communication; Drone; HTTP; Adaptive; Video; Streaming, Wi-Fi.*

I. INTRODUCTION

Wireless communication protocols play a critical role in enabling adaptive video streaming [11], [12] in drones [7]. As drones become increasingly popular for various applications, including surveillance, cinematography, and remote monitoring, the need for efficient and reliable video streaming capabilities becomes paramount [18]. To address this need, comprehensive taxonomies of wireless communication protocols have been developed to categorize and understand the protocols commonly used for adaptive video streaming in drones.

These taxonomies aim to provide researchers, developers, and practitioners in the drone industry with a systematic overview of the different wireless communication protocols available, their functionalities, and their suitability for adaptive video streaming. By organizing the protocols into well-defined categories, these taxonomies help in understanding the relationships and interdependencies between different protocols and their applications.

The first comprehensive taxonomy focuses on HTTP-based adaptive streaming protocols, such as Dynamic Adaptive Streaming over HTTP (DASH) [10] and HTTP Live Streaming (HLS) [20]. These protocols enable drones to adaptively stream video segments, adjusting the quality based on the available network conditions. Additionally, it includes real-time streaming protocols like Real-Time Transport Protocol (RTP) [8] and Real-Time Messaging Protocol (RTMP) [25], which are commonly used for real-time transmission of multimedia data, including video and audio. Transport protocols like User Datagram Protocol (UDP) [17] and Transmission Control Protocol (TCP) [13] are also covered, as they offer different trade-offs between low latency and reliability. Furthermore, the taxonomy encompasses wireless standards such as IEEE 802.11 Wi-Fi protocols [3] and 4G LTE/5G NR [2], which define the specifications for wireless communication over Wi-Fi networks and cellular networks, respectively.

The second comprehensive taxonomy expands on the first by introducing additional components and protocols. It includes cellular network protocols like 4G LTE and 5G NR [4], which provide higher data rates and low-latency connections suitable for real-time adaptive video streaming [29]. Wi-Fi protocols [24], satellite communication protocols [34], point-to-point wireless protocols [26], mesh networking protocols [5], and hybrid communication approaches are also discussed, providing a broader understanding of the communication options available to drones for adaptive video streaming.

These comprehensive taxonomies serve as valuable references for researchers, developers, and practitioners involved in designing and implementing adaptive video streaming solutions for drones. By providing a structured framework of wireless communication protocols, these taxonomies facilitate informed decision-making regarding protocol selection, optimization, and system design.

Ultimately, they contribute to enhancing the video streaming capabilities of drones, enabling them to deliver high-quality, adaptive video content in various applications and environments.

This paper consists of six sections. Section II introduces Adaptive Video Streaming (AVS) and provides scenarios with Drone applications. In Section III we discuss Drone technology. The multi-taxonomy, specifically two taxonomies are given in Section IV. We present a discussion of the taxonomies in Section V and a conclusion is given in Section VI.

II. ADAPTIVE VIDEO STREAMING

Adaptive video streaming is a technique used to dynamically adjust the quality of video content based on the available network conditions [14]. It ensures a smooth and uninterrupted video playback experience by adapting to variations in bandwidth, latency, and other network factors. Adaptive video streaming involves breaking down the video content into smaller segments of different quality levels. Each segment is encoded at various bitrates, representing different levels of video quality. These segments are then made available for streaming. When a video is being streamed, the client device, such as a drone or a user's device, continuously monitors the network conditions. It estimates the available bandwidth and evaluates the network's performance. Based on this information, the client device selects the appropriate video segment with the corresponding quality level that can be reliably delivered given the current network conditions. This process ensures that the video playback is smooth and uninterrupted.

In the case of flying vehicles like drones, adaptive video streaming is particularly important due to the dynamic nature of the network conditions. Drones often operate in areas with varying signal strengths, interference, and limited bandwidth. Adaptive streaming algorithms within the drone's communication system continuously monitor the network conditions, such as signal strength, latency, and available bandwidth. These algorithms dynamically adjust the quality of the video being streamed to ensure optimal video delivery.

We now give some advantages of adaptive video streaming include. Adaptive streaming ensures that viewers receive the highest possible video quality based on their network capabilities. It adapts to fluctuations in network conditions, minimizing buffering and providing a smooth playback experience. Also, by adapting the video quality to match the available network bandwidth, adaptive streaming optimizes bandwidth utilization. It prevents excessive data consumption and enables efficient use of network resources. In addition, adaptive streaming supports a wide range of devices and network conditions. It can deliver video content to different devices with varying capabilities, allowing for seamless playback across various platforms.

We now give some disadvantages of adaptive video streaming. Adaptive streaming requires the video content to be encoded at multiple quality levels, increasing the encoding complexity and storage requirements. Also, the adaptive streaming process introduces additional latency due to the need to monitor network conditions, select appropriate video segments, and adapt the streaming bitrate accordingly. This can result in a slight delay between the actual video content and its playback. Furthermore, implementing adaptive streaming techniques and managing the necessary infrastructure can be challenging for content providers, especially when delivering video content to a large audience. Despite these disadvantages, the benefits of adaptive video streaming, such as improved user experience and efficient bandwidth utilization, make it a widely adopted technique for delivering high-quality video content in various applications [23], including flying vehicles like drones.

We now give a scenario of a drone using adaptive video streaming for aerial surveillance. In a bustling city, a security company utilizes drones equipped with advanced camera systems for aerial surveillance. These drones are deployed to monitor public areas, providing real-time video feeds to the security personnel on the ground. To ensure optimal video quality and reliable transmission, the drones employ adaptive video streaming techniques. As the drone takes off, it establishes a wireless connection with the ground control station using a combination of Wi-Fi and cellular networks. The drone's camera captures high-definition video footage of the designated area, which is then processed and encoded in real-time. The adaptive video streaming algorithm running on the drone's communication system continuously monitors the network conditions. It takes into account factors such as signal strength, available bandwidth, and latency. Based on this information, the algorithm dynamically adjusts the quality of the video being streamed. For instance, if the drone encounters a congested Wi-Fi network or experiences low signal strength, the adaptive streaming algorithm intelligently lowers the video bitrate to ensure a smooth and uninterrupted transmission. It selects a lower quality video segment from the encoded versions, optimizing the video stream for the available network resources. Conversely, when the drone moves to an area with a robust cellular network or a stronger Wi-Fi signal, the adaptive streaming algorithm recognizes the improved network conditions. It then selects a higher quality video segment, allowing for sharper details and improved visual clarity in the video stream.

Throughout its flight, the drone's adaptive video streaming mechanism continuously assesses the network conditions and adapts the streaming bitrate accordingly. This ensures that the security personnel receive the best possible video quality in real-time, even in challenging environments with fluctuating network conditions. The advantages of adaptive video streaming become evident in this scenario. It enables the drone to dynamically adjust the video quality to match the available network resources, providing a smooth and uninterrupted video stream. This ensures that the security personnel can effectively monitor the area, identify potential threats, and make informed decisions based on high-quality visual information. Moreover, adaptive video streaming optimizes bandwidth usage, preventing excessive data consumption. This is particularly important for drones, as it allows them to operate within the limitations of their wireless communication systems, conserving battery life and ensuring efficient utilization of network resources. By employing adaptive video streaming, the drone's aerial surveillance capabilities are enhanced. It provides a reliable, high-quality video stream that enables security personnel to effectively monitor the area and respond promptly to any potential security concerns, contributing to enhanced public safety in the city.

We now give another scenario of a drone filming a sporting event with adaptive video streaming. In a sprawling stadium, a professional drone operator is tasked with capturing aerial footage of a thrilling sporting event. Equipped with a high-resolution camera and advanced communication capabilities, the drone utilizes adaptive video streaming to provide a seamless live streaming experience to sports fans around the world. Before the event begins, the drone establishes a wireless connection with the broadcasting control center using cellular networks. This connection allows for real-time video transmission from the drone to the broadcasting team, who will distribute the footage to viewers across various platforms. As the sporting event commences, the drone hovers above the stadium, capturing the action-packed moments from unique angles. The camera on the drone records the high-definition video, which is then encoded in real-time to be streamed to the broadcasting control center. The adaptive video streaming algorithm integrated into the drone's communication system constantly monitors the network conditions. It takes into account factors such as available bandwidth, network congestion, and latency to ensure a high-quality streaming experience.

During critical moments of the game or when network conditions are optimal, the adaptive streaming algorithm selects the highest quality video segments for transmission. This allows viewers to enjoy the game with crystal-clear visuals, capturing every detail of the players' movements and the excitement of the event. However, if the network experiences congestion or a decrease in available bandwidth, the adaptive streaming algorithm intelligently adjusts the video quality. It dynamically switches to lower bitrate video segments to ensure smooth playback and prevent buffering or interruptions, without compromising the overall viewing experience. This adaptive video streaming process ensures that sports fans watching the live stream receive the best possible video quality based on their network conditions. Whether they are watching on their smartphones, tablets, or computers, the adaptive streaming algorithm optimizes the video delivery, adapting to varying network capabilities.

The advantages of adaptive video streaming become evident in this scenario. It allows the drone to transmit high-quality footage in real-time, capturing the excitement of the sporting event. Viewers can enjoy the live stream without interruptions or buffering, thanks to the adaptive video streaming algorithm's ability to adapt to network fluctuations. Additionally, adaptive video streaming optimizes bandwidth usage, ensuring efficient utilization of network resources. This is particularly crucial during popular sporting events, where a large number of viewers may be simultaneously accessing the live stream. The algorithm ensures that the video stream is delivered effectively, without overloading the network infrastructure. By utilizing adaptive video streaming, the drone enhances the overall viewing experience for sports fans worldwide. It provides dynamic and high-quality footage, capturing the essence of the sporting event from unique aerial perspectives. The adaptive streaming algorithm enables seamless live streaming, connecting viewers to the action in real-time and keeping them engaged throughout the event.

We now give another scenario of a search and rescue drone with adaptive video streaming. In a rugged mountainous region, a search and rescue team deploys a specialized drone equipped with advanced imaging capabilities to locate a missing hiker. The drone leverages adaptive video streaming to transmit real-time video footage to the rescue team, aiding in their search efforts. As the search and rescue drone takes flight, it establishes a wireless connection with the ground control station using a combination of long-range communication technologies such as 4G LTE. This connectivity enables the drone to maintain a reliable and uninterrupted data link with the rescue team. Equipped with thermal imaging and high-resolution cameras, the drone starts scanning the area for any signs of the missing hiker. The captured video footage is processed and encoded in real-time for transmission to the rescue team. The adaptive video streaming algorithm embedded within the drone's communication system continuously assesses the network conditions and adjusts the video quality accordingly to optimize the search and rescue operation. During the search, if the drone encounters a region with limited network coverage or reduced bandwidth, the adaptive streaming algorithm intelligently selects lower quality video segments. This ensures that the rescue team still receives a usable video stream, albeit with a slightly reduced resolution. The focus here is on maintaining a stable connection and transmitting critical visual information to aid in the search effort. Conversely, when the drone flies over an area with robust network coverage and higher available bandwidth, the adaptive streaming algorithm automatically selects higher quality video segments. This enables the rescue team to access clearer and more detailed visuals, providing them with a better understanding of the terrain and potential obstacles.

The adaptive video streaming mechanism allows the drone to optimize the use of network resources and adapt to the ever-changing network conditions during search and rescue missions [6]. It ensures that the rescue team can receive vital video information in real-time, enabling them to make informed decisions and take prompt action. The advantages of adaptive video streaming in this scenario are particularly critical. It enables the search and rescue team to maintain a reliable and consistent visual feed, even in challenging and remote environments. By adapting to the network conditions, the adaptive streaming algorithm ensures that crucial video information reaches the rescue team without interruptions, improving the effectiveness and efficiency of the search operation. However, a disadvantage of adaptive video streaming in this scenario is the potential for increased latency due to the adaptive streaming process. The time taken to monitor network conditions, select appropriate video segments, and adapt the streaming bitrate can introduce a slight delay between the drone's footage and its real-time transmission. However, this latency is generally acceptable in search and rescue operations, as the priority is on transmitting usable visual information rather than real-time video synchronization. Thus, adaptive video streaming greatly enhances the capabilities of search and rescue drones. It enables real-time transmission of video footage, adapting to network conditions to ensure that critical visual information reaches the rescue team. By optimizing the video quality and utilizing available network resources efficiently, adaptive streaming aids in expediting search and rescue efforts, improving situational awareness, and increasing the chances of locating missing individuals in challenging environments.

III. DRONE TECHNOLOGY

Drone technology refers to the design, development, and utilization of unmanned aerial vehicles (UAVs), commonly known as drones [31]. These unmanned aircraft are equipped with various sensors, cameras, and communication systems that enable them to perform a wide range of tasks and capture valuable data from the air. One of the most crucial aspects of drone technology is the ability to capture and transmit video footage. Drones are equipped with high-resolution cameras that can capture imagery and videos from unique aerial perspectives. This capability has revolutionized industries such as photography, filmmaking, aerial surveillance, infrastructure inspections, agriculture, and search and rescue operations. The importance of video in drone technology lies in its ability to provide real-time situational awareness and valuable visual information. Video footage captured by drones offers a bird's-eye view of landscapes, structures, events, and activities that would otherwise be inaccessible or challenging to observe. This unique perspective allows for enhanced decision-making, analysis, and understanding of the environment.

In various industries, drones equipped with cameras provide valuable insights and data. For example, in agriculture [21], aerial video footage helps monitor crop health, identify irrigation issues, and assess field conditions. In infrastructure inspections [9], drones capture detailed videos of bridges, power lines, and buildings, aiding in maintenance and detecting structural anomalies. In aerial surveillance and law enforcement [28], drones equipped with video capabilities enable monitoring of large areas, crowd management, and swift response to emergency situations. Similarly, in search and rescue operations [19], drone video footage assists in locating missing persons, identifying hazards, and planning rescue missions. Moreover, the ability to stream video in real-time is of paramount importance. Live video feeds from drones [33] provide immediate visual feedback, allowing operators and stakeholders to make informed decisions on the spot. This is particularly valuable in time-sensitive scenarios such as disaster response, where real-time video can aid in assessing damage, coordinating rescue efforts, and deploying resources effectively.

The advancements in drone video technology, including adaptive video streaming, have further enhanced their utility. Adaptive video streaming techniques optimize video quality based on network conditions, ensuring smooth transmission and real-time visual feedback. This is critical for applications like live broadcasting, aerial surveys, and remote inspections where high-quality video delivery is essential. In general, drone technology and the importance of video go hand in hand. The ability to capture, transmit, and analyze video footage from drones has transformed various industries, providing unique insights, enhancing safety, and enabling more efficient and informed decision-making processes. As drone technology continues to evolve, video will remain a central element, driving innovation and unlocking new possibilities across numerous sectors.

IV. MULTI-TAXONOMY

A. Taxonomy 1

Here's a taxonomy of wireless communication protocols commonly used by drones for adaptive video streaming:

1. HTTP-based Adaptive Streaming Protocols

Dynamic Adaptive Streaming over HTTP (DASH): DASH is an adaptive streaming protocol that enables the delivery of video content over HTTP. Drones can utilize DASH to adaptively stream video segments, adjusting the quality based on the available network conditions.

HTTP Live Streaming (HLS): HLS is another HTTP-based streaming protocol commonly used for adaptive video streaming. It breaks video content into smaller chunks and dynamically adjusts the quality based on network conditions.

2. Real-Time Streaming Protocols

Real-Time Transport Protocol (RTP): RTP is a protocol used for real-time transmission of multimedia data, including video and audio. Drones can employ RTP in combination with other protocols to stream video in real-time with adaptive quality.

Real-Time Messaging Protocol (RTMP): RTMP is a protocol often used for streaming video and audio over the internet. While primarily associated with live streaming, drones can utilize RTMP for adaptive video streaming applications.

3. Transport Protocols

User Datagram Protocol (UDP): UDP is a lightweight transport protocol suitable for real-time streaming applications. Drones can utilize UDP for transmitting video data with low latency, but it may require additional mechanisms for congestion control and error recovery.

Transmission Control Protocol (TCP): TCP is a reliable transport protocol that ensures the ordered and error-free delivery of data. Although less common for real-time video streaming due to its potential latency and buffering issues, drones can still employ TCP for adaptive video streaming in certain scenarios.

4. Wireless Standards

IEEE 802.11 Wi-Fi Protocols: Drones equipped with Wi-Fi capabilities can utilize various IEEE 802.11 standards, such as 802.11a/b/g/n/ac/ax [27], for wireless video streaming. These standards define the physical and MAC layer specifications for communication over Wi-Fi networks.

4G LTE and 5G NR: Drones equipped with cellular connectivity can utilize 4G LTE or 5G networks to stream video in real-time. These standards provide higher data rates and low-latency connections suitable for adaptive video streaming.

It's important to note that the choice of protocols for adaptive video streaming on drones depends on factors such as network conditions, available bandwidth, latency requirements, and the specific video streaming application. Drones may employ a combination of these protocols to optimize video quality and maintain a smooth streaming experience while considering the constraints of wireless communication.

B. Taxonomy 2

Here's another taxonomy for wireless communication protocols used by drones for adaptive video streaming:

1. Cellular Network Protocols

4G LTE (Long-Term Evolution): Drones equipped with cellular connectivity can utilize 4G LTE networks to stream video in real-time. LTE offers high data rates, low latency, and wide coverage, making it suitable for adaptive video streaming applications.

5G NR (New Radio): As 5G networks become more prevalent, drones can leverage 5G NR to achieve even higher data rates, ultra-low latency, and improved network capacity, enabling seamless adaptive video streaming.

2. Wi-Fi Protocols

IEEE 802.11ac/ax (Wi-Fi 5/6 [22]): Drones equipped with Wi-Fi capabilities can utilize the latest Wi-Fi standards to establish wireless connections and stream video. Wi-Fi 5 (802.11ac) and Wi-Fi 6 (802.11ax) offer higher throughput, increased capacity, and improved performance, enabling efficient adaptive video streaming.

3. Satellite Communication Protocols

SATCOM (Satellite Communication): Drones operating in remote areas or beyond the range of traditional wireless networks can employ satellite communication protocols. SATCOM enables long-range communication and can support adaptive video streaming, providing coverage in areas where other wireless options are limited.

4. Point-to-Point Wireless Protocols

Drones can use point-to-point microwave links to establish dedicated wireless connections for video streaming. These links operate in licensed frequency bands and offer high data rates, low latency, and long-range connectivity, making them suitable for adaptive video streaming in specific applications.

5. Mesh Networking Protocols

Drones can form ad hoc mesh networks [16], where they communicate directly with each other to create a self-configuring network infrastructure. This enables collaborative video streaming, where drones share video feeds among themselves and adaptively adjust video quality based on network conditions within the mesh.

6. Hybrid Communication Approaches

Drones can employ hybrid communication approaches by simultaneously utilizing multiple wireless interfaces, such as Wi-Fi and cellular, or satellite and Wi-Fi, to ensure reliable and adaptive video streaming [32]. These approaches improve the resilience of the communication link and enhance the overall streaming experience.

7. Peer-to-Peer Protocols:

Peer-to-peer (P2P) protocols for drones [15] enable decentralized video streaming by allowing drones to share video segments directly with each other. P2P protocols establish a network where drones act both as content consumers and content providers, collectively forming a distributed video streaming infrastructure.

The taxonomy highlights a range of wireless communication protocols available for drones engaged in adaptive video streaming. The selection of protocols depends on factors such as coverage requirements, available infrastructure, bandwidth needs, and the specific application context. Drones may employ a combination of these protocols to optimize video quality, ensure reliable connectivity, and adapt to changing network conditions.

V. DISCUSSION

A. Taxonomy 1

The taxonomy of wireless communication protocols commonly used by drones for adaptive video streaming provides a comprehensive overview of the components involved in the streaming process and their relationships. Let's discuss these components and their interconnections:

1. HTTP-based Adaptive Streaming Protocols:

DASH and HLS are two widely adopted protocols that enable adaptive video streaming over HTTP. Both protocols segment the video content and dynamically adjust the quality based on network conditions. Drones can choose to implement either protocol depending on their requirements and compatibility with the receiving devices or platforms.

2. Real-Time Streaming Protocols:

RTP is a protocol designed for real-time transmission of multimedia data. Drones can utilize RTP along with other protocols to stream video in real-time with adaptive quality. RTP provides mechanisms for time-stamping, sequence numbering, and payload type identification, which are essential for real-time video streaming applications.

RTMP is commonly associated with live streaming, but drones can also employ it for adaptive video streaming. RTMP offers low-latency transmission and supports adaptive bitrate streaming, making it suitable for dynamic video quality adjustments.

3. Transport Protocols:
UDP is a lightweight transport protocol that is often used for real-time streaming applications. Drones can leverage UDP for transmitting video data with low latency, as it does not have the overhead of TCP. However, additional mechanisms for congestion control and error recovery may be required.

TCP, although less common for real-time video streaming due to potential latency and buffering issues, can still be used by drones for adaptive video streaming in certain scenarios where reliable and ordered delivery of data is crucial.

4. Wireless Standards:
IEEE 802.11 Wi-Fi Protocols encompass various standards like 802.11a/b/g/n/ac/ax, which define the physical and MAC layer specifications for communication over Wi-Fi networks. Drones with Wi-Fi capabilities can utilize these standards for wireless video streaming, taking advantage of the available bandwidth and features supported by each standard.

4G LTE and 5G NR are cellular network standards that offer higher data rates and low-latency connections. Drones equipped with cellular connectivity can leverage these standards to stream video in real-time, providing greater coverage and mobility compared to Wi-Fi.

The taxonomy highlights the flexibility and variety of protocols available for adaptive video streaming on drones. The selection of protocols depends on factors such as network conditions, available bandwidth, latency requirements, and the specific video streaming application. Drones may utilize a combination of these protocols to optimize video quality and ensure a smooth streaming experience while considering the constraints and capabilities of wireless communication.

B. Taxonomy 2
The taxonomy of wireless communication protocols used by drones for adaptive video streaming provides a comprehensive overview of the components involved in establishing wireless communication and delivering adaptive video content. Let's discuss the components and their relationships within this taxonomy:

1. Cellular Network Protocols:
4G LTE and 5G NR are cellular network protocols that enable drones to utilize cellular networks for real-time video streaming. These protocols provide high data rates, low latency, and wide coverage, allowing drones to transmit video over long distances and adapt the streaming quality based on network conditions.

2. Wi-Fi Protocols:
IEEE 802.11ac/ax (Wi-Fi 5/6) standards offer drones the ability to establish wireless connections for video streaming. Wi-Fi protocols provide higher throughput, increased capacity, and improved performance, enabling efficient adaptive video streaming within a localized area.

3. Satellite Communication Protocols:
SATCOM protocols enable drones to communicate via satellites, extending their range and coverage beyond traditional wireless networks. Satellite communication is particularly valuable in remote areas where terrestrial connectivity may be limited. Drones can utilize satellite communication protocols to stream video in real-time, ensuring adaptive quality even in challenging environments.

4. Point-to-Point Wireless Protocols:
Microwave links enable drones to establish dedicated wireless connections for video streaming. These protocols operate in licensed frequency bands and offer high data rates, low latency, and long-range connectivity. Drones can utilize point-to-point wireless protocols for adaptive video streaming in scenarios where a dedicated communication link is required.

5. Mesh Networking Protocols:
Ad hoc mesh networking allows drones to form a self-configuring network infrastructure, enabling collaborative video streaming. Drones communicate directly with each other within the mesh, sharing video feeds and adapting the streaming quality based on network conditions. Mesh networking protocols facilitate dynamic and adaptive video streaming within a swarm or group of drones.

6. Hybrid Communication Approaches:
Drones can employ hybrid communication approaches by simultaneously utilizing multiple wireless interfaces. For example, using both Wi-Fi and cellular connections or combining satellite and Wi-Fi links. These hybrid approaches enhance the resilience of the communication link, providing backup options and ensuring adaptive video streaming in diverse scenarios.

7. Peer-to-Peer Protocols:
Peer-to-Peer (P2P) Protocols: Drones can leverage P2P protocols for decentralized video streaming. In P2P networks, drones share video segments with each other, reducing the load on individual nodes and enabling adaptive streaming based on network conditions within the network.

The taxonomy illustrates the relationships between different wireless communication protocols. Drones can select the appropriate protocol(s) based on factors such as coverage requirements, available infrastructure, bandwidth needs, and the specific application context. In some cases, drones may employ multiple protocols in a hybrid fashion to optimize video quality, ensure reliable connectivity, and adapt to changing network conditions. Furthermore, the taxonomy acknowledges the importance of adaptive video streaming, which allows drones to dynamically adjust the video quality based on network conditions. This ensures a smooth streaming experience, even in challenging wireless environments, and optimizes the utilization of available bandwidth. In general, this taxonomy presents a comprehensive framework for understanding the components and relationships between wireless communication protocols used by drones for adaptive video streaming. It highlights the versatility and flexibility of these protocols, enabling drones to capture, transmit, and deliver high-quality video content in real-time, while adapting to the constraints and opportunities of wireless communication.

We now delve into Peer-to-Peer protocols a bit further. In a P2P network, each drone participating in the video streaming process is referred to as a peer. These peers establish direct connections with each other, enabling the exchange of video segments without relying on a centralized server. This decentralized architecture offers several benefits, including scalability, robustness, and efficient resource utilization.

The technical implementation of P2P protocols for drones involves several key components and processes. Drones need a mechanism to discover and connect with other peers participating in the P2P network. Peer discovery protocols enable drones to find and establish connections with neighboring drones within the network. Common approaches include centralized trackers, distributed hash tables (DHTs) [1], or local area network (LAN) scanning techniques [27].

Once connected, drones can exchange video segments with each other to distribute the streaming content. This process involves dividing the video into smaller chunks, typically called segments, and sharing them among the peers. Each peer contributes by providing segments it possesses and requesting missing segments from other peers. This cooperative sharing allows for load balancing and redundancy in the network.

As video segments are exchanged among peers, it is crucial to ensure synchronization to maintain a seamless streaming experience. Peers need to coordinate their actions, such as segment availability, playback time, and quality adaptation. Synchronization mechanisms ensure that drones receive the appropriate segments in the correct order, minimizing playback interruptions and maintaining synchronization across the network.

P2P protocols for drones should also incorporate mechanisms for adaptive video streaming. Peers monitor network conditions and dynamically adjust the video quality based on available resources and playback requirements. Quality adaptation algorithms consider factors such as bandwidth, latency, and buffer occupancy to optimize the video quality delivered by each peer.

P2P networks can be susceptible to disruptions, including drone disconnections or segment unavailability. Protocols need to incorporate error recovery mechanisms to handle these situations. Techniques such as forward error correction (FEC), retransmission, or redundancy-based approaches ensure reliable content delivery and maintain a consistent streaming experience.

P2P protocols should include mechanisms for efficient network management. This includes handling network dynamics, such as peer joins and departures, load balancing, and optimizing the routing paths for data exchange. Efficient network management ensures the stability, scalability, and performance of the P2P network for video streaming.

P2P protocols for drones leverage the collaborative power of the drones themselves, enabling efficient and scalable video streaming in scenarios where centralized infrastructure may be unavailable or impractical. By distributing the streaming workload among peers, P2P protocols enhance resilience, reduce dependency on single points of failure, and enable adaptive video streaming in challenging wireless environments.

VI. CONCLUSTION

In conclusion, the two taxonomies provided offer a comprehensive overview of the wireless communication protocols commonly used by drones for adaptive video streaming. These taxonomies highlight the diverse range of protocols available and their specific applications in the drone industry. The first taxonomy emphasizes the importance of HTTP-based adaptive streaming protocols such as DASH and HLS, which enable drones to dynamically adjust video quality based on network conditions. It also includes real-time streaming protocols like RTP and RTMP, which facilitate the real-time transmission of video content. The taxonomy further considers transport protocols like UDP and TCP, which provide different trade-offs between low latency and reliability. Lastly, it covers wireless standards such as IEEE 802.11 Wi-Fi protocols and 4G LTE/5G NR for wireless video streaming. The second taxonomy expands on the first by introducing additional components. It includes cellular network protocols like 4G LTE and 5G NR, which offer higher data rates and low-latency connections suitable for real-time adaptive video streaming. Wi-Fi protocols, satellite communication protocols, point-to-point wireless protocols, mesh networking protocols, and hybrid communication approaches are also discussed. These components provide a broader understanding of the communication options available to drones for adaptive video streaming. Both taxonomies highlight the importance of adaptive video streaming, allowing drones to dynamically adjust the video quality based on network conditions. This ensures a seamless streaming experience, optimal bandwidth utilization, and improved video delivery over wireless networks. The choice of protocols depends on various factors such as coverage requirements, available infrastructure, and the specific application context. These taxonomies provide valuable insights into the wireless communication protocols used by drones for adaptive video streaming. They serve as a foundation for understanding the components, relationships, and considerations involved in establishing reliable and efficient wireless connections for high-quality video streaming in the drone industry.

ISSN No:-2456-2165

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