# Poster Abstract: Wireless Access to Ultimate Virtual Reality 360-Degree Video

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## ABSTRACT

Virtual reality 360-degree videos will become the first prosperous online VR application. In this paper, we focus on the ultimate VR 360 that satisfies human eye fidelity. The ultimate VR 360 requires downlink 1.5 Gbps for viewing and uplink 6.6 Gbps for live broadcasting, with the round-trip-time of less than 8.3 ms. We explore whether the most advanced wireless communication technologies support the ultimate VR 360. Specifically, we consider 5G in cellular communications, IEEE 802.11ac (operating in 5 GHz) and IEEE 802.11ad (operating in 60 GHz) in WiFi communications. Our results indicate the need for more advanced wireless technologies to fully support the ultimate VR 360. It requires further research to build VR 360 systems within Internet-of-Things platforms.

## CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**;

## KEYWORDS

Virtual Reality, Wireless Communications, 5G, 802.11ac, 802.11ad

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## 1 INTRODUCTION

As the next-generation Internet platform, Virtual Reality (VR) has aroused great interests in academia and industry [2]. It has two forms of applications: viewing and live broadcasting. In VR 360 viewing, a user wears a VR headset that blocks outside view so that the user immerses only on what is being displayed on the headset. The user watches a part of the view, termed as Field-of-View (FoV), while the full-view video is captured $360^o$ horizontally and $180^o$ vertically. In VR 360 live broadcasting, a user uploads live video streams to social media, e.g., Facebook and YouTube, using 360-degree cameras, and meanwhile the video is watched by other online users with VR headsets [7]. VR and IoT are a natural fit in creating informative and interactive environments. Fig. 1 shows an example of combining IoT and VR in creating active virtual classrooms. In this example, IoT technologies exploit multiple connected sensors to infer, e.g., students' gestures, while VR leverages the gesture information from IoT to create active virtual classrooms. With such combination of IoT and VR, students can have vivid experience such as learning dinosaurs. Without IoT support, VR can only render passive panoramic videos which reduces students' interactivity. In addition to the virtual classrooms, the combination of IoT and VR has many applications in manufacturing, transportation, and utilities [3]. As IoT systems are becoming increasingly powerful which are capable of transmitting high-speed data with recent wireless transmission modules, we could leverage IoT systems to convey VR streaming contents, rather than build two systems of IoT and VR which incurs higher infrastructure cost and management difficulty.

In this paper, we focus on the ultimate VR 360 that satisfies human eye fidelity. An ultimate VR video is encoded with 64 Pixels Per Degree (PPD), 12 bit color-depth and 120 Frames Per Second (FPS). The corresponding video bit rate is 2.3 Tbps. The near-future video compression technique, e.g., H.266, is expected to achieve a compression ratio of 350:1. This reduces the data rate of streaming an ultimate VR 360 video to 6.6 Gbps. A further data rate reduction can be realized in VR 360 viewing by leveraging part-view transmission ($120° \times 120°$ instead of $360° \times 180°$), resulting in 1.5 Gbps data rate. Therefore, the ultimate VR 360 video requires networking infrastructure that supports 1.5 Gbps downlink for viewing and 6.6 Gbps uplink for live broadcasting, with the round-trip-time (RTT) of less than 8.3 ms (video frame refresh interval of 120 FPS). One interesting question is whether existing wireless communication technologies can support the ultimate VR 360 videos, which have the potential to enlarge the applications of IoT systems. Considering the demanding data rate and latency of the ultimate VR 360, we explore whether the most advanced wireless technologies from both cellular and WiFi communications can support the ultimate VR 360. Specifically, we consider 5G in cellular communications, IEEE 802.11ac and IEEE802.11ad in WiFi communications.

## 2 ADVANCED WIRELESS TECHNOLOGIES

For each selected wireless communication technology, we survey its development/deployment status and technology features, as well as the performance determined by its standard specification and/or empirically measured.

### 2.1 5G

**Deployment Status**. The fifth generation cellular communication, i.e., 5G, is expected to be standardized by the early 2020s. Its design target is to achieve 10-100x peak data rate, 1000x network capacity, 10x energy efficiency, and 10-30x lower latency compared to its predecessor of 4G. Because of the exciting performance that 5G promises, the industry has already been building 5G ecosystems.


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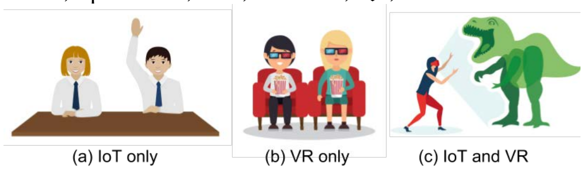



**Figure 1: An example of IoT and VR in classrooms. (a) Gesture inference with IoT only; (b) Passive panoramic videos with VR only; (c) Active virtual classrooms with IoT and VR**

For example, AT&T started to deploy its 5G network in late 2018, and expects to reach 19 cities in early 2019; Qualcomm unveiled its 5G millimeter-wave module for smartphones in July 2018, and the first 5G smartphone is expected to come out in 2019.

**Technology Features**. The data rate improvement of 5G over 4G mainly thanks to the following three technology categories: extreme densification and offloading, millimeter wave, and massive Multiple-Input and Multiple-Output (MIMO) [1].

**System Performance**. Since 5G has not been fully standardized yet, its maximum achievable performance is not determined. However, 5G systems in line with IMT-2020 specifications are expected to provide 1 Gbps user experience data rate and 1 ms RTT.

## 2.2 IEEE 802.11ac

**Deployment Status**. IEEE 802.11ac is an evolution from IEEE 802.11n. The first AC router (Netgear R6300) was released in 2012 and the first AC-complaint smartphone (Samsung Mega) came out in 2013. Afterwards, more smartphones are equipped with AC WiFi modules. AC functionality is now the standard specification of new smartphones. Despite having been on markets for several years, existing AC modules are far from the full capacity of IEEE 802.11ac standard. For example, the AC standard allows 8 spatial streams, while current AC devices can only support up to 4 spatial streams.

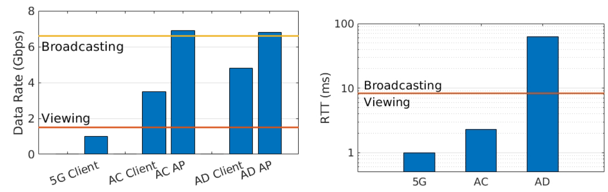
**Technology Features**. IEEE 802.11ac improves over IEEE 802.11n in many aspects, including wider channels (up to 160 MHz), 256-QAM support, simplified beamforming, more spatial streams and multi-user MIMO (MU-MIMO) [4].

**System Performance**. Once the channel bandwidth, Modulation and Coding Scheme (MCS), Number of Spatial Streams (NSS) and Guard Interval (GI) are determined, the data rate of AC devices can be found by looking up the data rate table. A full-fledged AC access point (AP) supports a 160 MHz channel, MCS of 9, NSS of 8, and short GI, and the corresponding data rate is 6.9 Gbps. The capacity of a full-fledged AC client only differs from an AC AP with regards to the number of spatial streams. An AC client supports 4 spatial streams (NSS=4), with data rate of 3.5 Gpbs. To roughly quantify AC networking RTT, we use two PC Engine APU2 development boards with AC modules (model: WLE650V5-18) that are closely placed, and ping each other, which gives an average RTT of 2.3 ms.

## 2.3 IEEE 802.11ad

**Deployment Status**. IEEE 802.11ad was standardized in 2012. The first AD router (TP-link AD7200) was released in May 2016 and the first AD-compatible smartphone (ASUS Zenfone 4 Pro) came out in September 2017. The market adoption of IEEE 802.11ad is not as successful as IEEE 802.11ac. However, as the first 802.11 standard on millimeter wave communication, IEEE 802.11ad was specifically designed to provide Gbps networking.

**Technology Features**. IEEE 802.11ad differs from legacy WiFi in many aspects including unique channel propagation behavior, novel beam training, and hybrid MAC channel access [5].




(a) Data Rate Comparison (b) Latency Comparison

**Figure 2: Performance of 5G, IEEE 802.11ac and IEEE 802.11ad versus ultimate VR 360 requirements**

**System Performance**. Similar to IEEE 802.11ac, the standard of IEEE 802.11ad specifies data rates that are supported. For example, an AD AP achieves its maximum data rate using Orthogonal Frequency-Division Multiplexing (OFDM), 64-QAM, 13/16 code rate, 6 coded bits per single carrier ($N_{BPSC}$), 2016 coded bits per symbol ($N_{CBPS}$), 1638 data bits per symbol ($N_{DBPS}$). The corresponding data rate of an AD AP is 6.8 Gbps. An AD client adopts more energy-efficient transmission scheme of Single Carrier (SC) rather than OFDM, and achieves maximum data rate of 4.6 Gbps when $\pi/2$-16QAM, 4 $N_{CBPS}$, and 3/4 code rate are used. To roughly quantify AD networking RTT, we ping an AD router (Netgear Nightnhawk X10) from a closely located AD laptop (Acer TravelMate P), which gives an average RTT of 62.7 ms.

## 2.4 Preliminary Results and Discussions

Fig. 2(a) shows the data rate supported by 5G, AC and AD, and the data rate requirement of the ultimate VR 360 videos. 5G does not provide high enough speed for the ultimate VR 360. IEEE 802.11ac and IEEE 802.11ad have similar data rate support at AP side and client side: both support the ultimate VR 360 viewing but fail to work when it comes to the ultimate VR 360 live broadcasting because the clients cannot upload at sufficient throughput. Fig. 2(b) shows the corresponding RTTs of 5G, AC, and AD, and compares it with the latency requirement of the ultimate VR 360. Briefly, 5G and AC have acceptable RTTs; the current implementation of IEEE 802.11ad, however, incurs very high latency, probably due to the delays from beam tracking and alignment [6]. In summary, only IEEE 802.11ac supports the ultimate VR 360 viewing. With further implementation optimization, IEEE 802.11ad is also potential to support it. However, none of them are capable of supporting the ultimate VR 360 live broadcasting. Our results indicate the need for advanced wireless technologies to fully support the ultimate VR 360. It requires further research efforts to build VR 360 within IoT platforms.

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