5G at the U.S. Open: Live Streaming Without the Handicap

Can 5G replace miles of fiber to broadcast live, high-definition sports video? A case study.

AT&T Business

FOX SPORTS

FOX LAB INNOVATION

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AT&T, Ericsson, FOX Sports, Fox Innovation Lab, and Intel team up to broadcast 4K video wirelessly over 5G at 2018 U.S. Open

Part I: Pre-game
The quest for a great spectator experience

Few customers are more demanding than sports fans—demanding of the athletes to perform on the green or on the field and demanding of their network to deliver the action as it happens, in vivid high definition, on every device, without a sputter.

FOX Sports is acutely aware of their viewers' high expectations for Quality of Experience (QoE). They also know well that growing demands for higher resolution video and more interactive, personalized sports experiences makes live production and delivery of content at sporting events complex and challenging. Communication from cameras to the production compound requires laying event-specific fiber, establishing local compute capability, and specialized equipment. For the U.S. Open alone, more than 39 miles of fiber was laid, and then removed, on the golf course. At some other sporting events, fiber demands can exceed 48 miles.

Snaking wires and equipment on the grounds can surely spoil the experience for both golfers and spectators. And the time, cost, labor and supplies required for a short-lived set-up are a challenge for broadcasters like FOX Sports. 5G wireless is an ideal solution for enhancing the pleasure and reducing the costs associated with live broadcasts of a golf tournament.

Mikael Bäckström, Head of Global Customer Unit AT&T at Ericsson, points out that "5G enables new and innovative use cases across a variety of industries and experiences, including sporting events. This was clearly demonstrated at the U.S. Open with a LIVE 4K broadcast where we delivered a high-speed, low-latency 5G solution." 5G has the potential to be the reliable platform for enhanced video service delivery that broadcasters like FOX Sports need to meet both their technical and business challenges. The new wireless technology enables multi-gigabit speeds with ultra-low latency, opening up new use cases as it boosts current ones.

Can 5G be a valid platform for enhanced video service?
This case study examines the groundbreaking trial conducted by FOX Sports and Fox Innovation Lab, alongside AT&T, Ericsson and Intel, at the 118th U. S. Open Championship in June 2018, to use mmWave 5G cellular technology to stream 4K video for potential broadcast nationwide. AT&T provided the required spectrum to optimize the 5G performance; Ericsson provided the 5G network equipment, including radios, baseband, simulated network core and 4K video encoder and decoder; Intel supplied the Intel® Mobile Trial Platform, working as the 5G modem or "phone."

By showcasing a powerful use case for reducing live production costs while enabling ultra-high-definition (UHD) broadcasting to scale, the trial establishes 5G as a reliable platform and represents a revolution in the way sports and media are distributed and consumed, and how users engage with an event.

"The collaboration with FOX Sports, AT&T and Ericsson to 'unplug the wires' at the U.S. Open Golf Tournament and broadcast the golf action on DirecTV is just an example of what can be achieved with mmWave spectrum for extreme capacity and throughput. Intel provided the ultra-high-speed Intel® 5G Mobile Trial Platform helping all partners to reimagine the future for live sports broadcasts and immersive entertainment through 5G."
— Asha Keddy, vice president and general manager, Next Generation and Standards at Intel Corporation.

Behind the test: Broadcasters confront growing demand

The U.S. Open 5G test wasn't simply an academic exercise but a recognition that we must be proactive in confronting the mobile data traffic explosion, thanks to our ballooning love of video. Forecasters expect that in six years, more than 74% of all mobile data will be video. Video traffic will reach more than 100 exabytes a month.[1,2]

This growth will be driven by such industries as media and entertainment, public safety and security. Consumers, alongside businesses, will be creating and sharing videos (uplink) and viewing video content (downlink) through social media and video streaming sites, placing significant demands on wireless networks alongside business demands. Ensuring a quality experience for all customers with this large and complex mix of data traffic won't be simple for mobile network operators.

Trials like the U.S. Open 5G test provide opportunities for AT&T and its partners to develop competencies for optimizing and delivering high quality mobile video and thereby build a foundation for providing superior performance for the largest category of mobile traffic.

1. Ericsson; "Mobility Report", November 2018
2. Calculate the traffic impact of different application categories: www.ericsson.com/mobility-report/ mobility-calculator

The 411 on 4K and 360-degree video

Mobile video comes in many forms, from YouTube, auto-play advertisements, social media, TV, movies or live broadcasts like news and sports. Streaming video up to a site or down to your mobile device requires significant throughput over the wireless networks. Ultra-high-definition (UHD), or 4K, video streaming significantly increases the amount of data sent and received. This chart illustrates how varying the quality of the video can change the consumption of data dramatically.

For the purposes of illustration, let's assume that we want to view a one-hour video with a fixed relationship of 60 frames per second and Standard Dynamic Range (SDR).[3] The chart compares the data usage and connection-speed requirements for delivering compressed production quality video from different video types—low, standard definition (SD), high definition (HD) and ultra-high-definition (UHD). As you can see, upgrading from SD to UHD produces 17 times more data for the same one-hour video. To maintain the desired 60 frames per second, the network must deliver 17 times more speed.

Even more impactful is an emerging trend of streaming immersive video formats, such as 360-degree and Virtual Reality video.

Assumes: Production quality video compressed at 60 frames per second

Video Type		Required Connection Speed	Usage Per Hour
Low	360p	1.5 Mbps	0.67 GB
SD	480p	4 Mbps	1.8 GB
HD	720p	7.5 Mbps	3.3 GB
	1080p	12 Mbps	5.4 GB
	1440p (2k)	24 Mbps	10.8 GB
UHD	2160p (4k)	68 Mbps	30.6 GB

For example, a YouTube 360-degree video consumes four to five times as much bandwidth as a normal HD YouTube video at the same resolution. Not only individuals but brands, businesses, marketing and creative industries have embraced the technology to engage audiences. The 360-degree camera market is expected to grow from 347.7M in 2017 to $1.5B in 2023.[4]

Moreover, every transmission needs to be compressed to take less of the network resources while maintaining the quality of the images. In the case of live transmission of UHD video, complexity is increased due to the large amounts of data. It takes time to apply compression. This delay is referred to as compression latency. In non-real-time situations, compression latency is not a factor. But in a real-time scenario such as live streaming of a sports event, the more compression used, the longer the latency. Therefore, live streaming for mobile network operators will become increasingly complex.

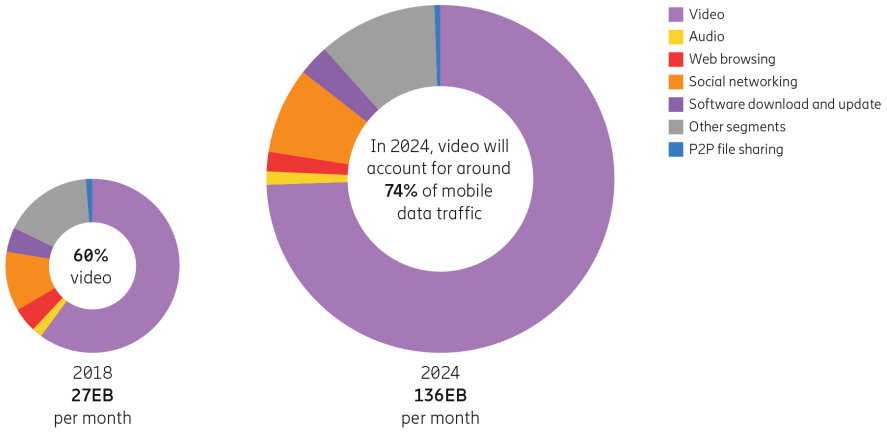
3. https://communityforums.rogers.com/t5/Rogers-Community-Forums-Blog/4K-Facts-SDR-vs-HDR-What-s-the-Difference/ba-p/339522
4. Markets and Markets, "360-Degree Camera Market to Reach $1.5B by 2023"; July 2018

Live Video Streaming:
In the future, will broadcasters compete with their own consumers for wireless bandwidth?

While cellular service providers have been pursuing solutions for streaming live video smoothly to their viewers (downlink), they're discovering that their customers have an insatiable appetite for uploading live video from their mobile devices (including smartphones, tablets, and portable video cameras).

The popularity of live video streaming and social media shares is driving significant spikes in uplink traffic which competes for future network resources the broadcaster needs. For example, in the 2018 Super Bowl, Wi-Fi traffic grew by 65%—but cellular traffic was more than twice the Wi-Fi traffic, hitting an all-time high of 36.5 terabytes—equivalent to 2.25 years of binge watching HD video—during the game.[5]

Mobile data traffic by application category per month (percent)



Ericsson Mobility Report November 2018

The rapid growth of consumer mobile video impacts enterprise network needs

Though forecast to be only 5% of total mobile video traffic, live video streaming on mobile devices is projected to grow 39 times from 2016-2021. Growth of worldwide mobile-based live video streaming is forecasted to reach 2.02 exabytes by 2021.[6] (For quick conversion, 52 petabytes equal 52 million gigabytes, while 2.02 exabytes equal 2.2 billion gigabytes). Both the uplink and downlink of live video put stringent demands on the throughput and latency of the wireless networks. As consumers create, stream and consume rich, high quality video on mobile devices, increased network demands occur on the resources needed by businesses like the media and entertainment industry.

The roar of the crowds: Covering live sporting events has massive demands

Now that we understand consumer demands on the network, let's return to the impact of media and entertainment industry needs in covering these live events.

In the U.S., we can identify 35 pinnacle sporting events in a given year including the U.S. Open, Daytona 500, Super Bowl, FIFA World Cup and Women's World Cup, MLB All-Star Game, Playoffs and World Series. In addition, there are hundreds of other significant sporting events, and thousands of second-tier sporting events, each attracting a fan base of tens of thousands. For example, there are more than 1300 football games on just the largest Division 1 college campuses and professional football stadiums that pull a fan base of 40,000 people. The estimate of ten times growth in video on mobile networks by 2023 may actually be a highly conservative (if not unrealistic!) estimate.

At these large events like the U.S. Open, the broadcast company can transmit nearly 2.2TB of data to broadcast the event—or the equivalent of almost 130 days of standard definition YouTube videos.[7]

Finding the ideal arena for a high-stakes business challenge

The U.S. Open 2018 5G test was driven by two business challenges:

> Broadcasters, service providers and other stakeholders are searching for ways to design, build and manage the impact of high-definition video streaming for critical business communication while maintaining a quality experience for consumers
> They need to accomplish all that while meeting business imperatives to control production costs

The participants in the trial recognized that in light of all the developments we've discussed above, the entertainment space is ripe for innovation that would solve such business challenges as:

> Engaging the audience with new fan experiences (at the event and at home)
> Reducing broadcast production costs and
> Improving the quality of the event coverage

To accomplish these goals, wireless networks must reliably transmit large amounts of data at very high speeds (throughput) with no noticeable delay (latency) while ensuring the video has no degradation in quality. These often have opposing impacts—higher quality of the data packets may slow speed or throughput. Network services and edge computing must be properly configured in order to begin transforming the business processes and fan experience.

Moving the computing power of the cloud out of a remote data center to the edge of the wireless network will enable the ultra-low latency needed for immersive fan experiences like Virtual Reality 360-degree, as well as wireless applications for other industries like collaborative robotics, autonomous vehicles and real-time remote control of machines.

The U.S. Open trial provided an opportunity to focus on reducing production costs by transforming a current business process. "5G will be transformational for business and will enable us to design better products and services in line with our industry focus. It is becoming clear to everyone that 5G is a game changer and I can't think of a better sport to start with than golf," said Robert Boyanovsky, Vice President-Enterprise Mobility at AT&T Business

As we detailed earlier in this case study, communication from cameras to the production compound today requires laying event specific fiber, establishing local compute capability, and deploying specialized equipment. This significant, yet temporary, set-up calls for significant investment in time, expense, and physical coordination of labor and supplies to lay and remove fiber and to host the on-site production equipment for producing and packaging the video for distribution to the viewers.

5. https://www.techrepublic.com/article/data-usage-at-super-bowl-52-grew-48-as-social-media-use-skyrockets/
6. Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021; February 7, 2017
7. https://www.androidcentral.com/how-much-data-does-streaming-media-use

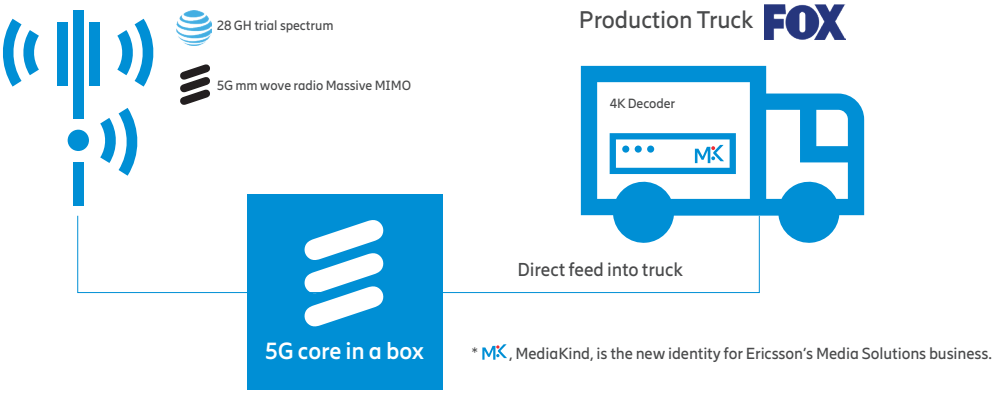
Part II: The Solution
5G changes the game

If the U.S. Open was the ideal testing ground, 5G promised to be the ideal solution for the future of live video broadcasting. AT&T, Ericsson and Intel partnered to test the delivery of FOX Sports UHD video streaming for two 4K cameras on the 7th green and tee box of the 2018 U.S. Open at Shinnecock Hills, NY. The objective of the trial was to prove that a 5G network could reliably send large, UHD video files with no detectible delays (latency) and no degradation to video quality transmitting at very high speeds (throughput).

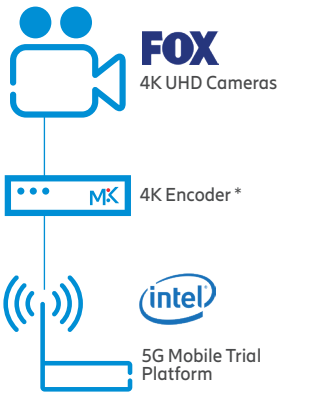
The solution can be summarized in four steps:

1. Compress video — convert (or encode) raw UHD live broadcast camera quality video
2. Efficiently prepare and route the video to the 5G radio network, proving that 5G can effectively handle large volumes of data uploaded from multiple cameras
3. Demonstrate 5G as a viable replacement for fiber. A key requirement of the trial was to upload large volumes at high speeds with very little packet loss or degradation of quality from the transmission point to the production compound
4. Convert compressed data into broadcast quality video at the on-site production compound and decode the UHD live video with no detectible loss in quality

Proof-of-Concept Solution



Camera Location at 7th Tee & Green



Uplink speeds way better than par

Delivery of encoded 4K video feeds from the golf course to the production compound required data rates of 60 to 80Mbps. Based on national speed tests, today's LTE networks across all mobile operators provide uplink speeds that average around 8-12Mbps, with peaks maxing out at 25Mbps. This is not sufficient for 4K UHD broadcast video transmission.[8] New large blocks of high frequency spectrum greatly enhance capabilities for 5G networks.

5G networks are best described as platforms that will ultimately have the ability to be configured to meet the needs of specific use cases. The 5G trial network at the U.S. Open was deployed around the 7th tee and green and demonstrated sustained uplink speeds of over 300Mbps throughout the entire event, easily meeting the per UHD camera requirement of 80Mbps. Additionaly, the low latency of 5G, observed at under 10ms for the event, showed that transmissions over 5G have no humanly observable delay difference compared with transmissions over fiber. AT&T, Ericsson and Intel proved that the end-to-end transmission could be properly configured to quickly upload large volumes of UHD broadcast-grade video, while maintaining the quality and stability of the transmission.

Mobile networks have the advantage of providing access over a large geographic area but have not historically been built to meet these stringent requirements. Instead of being a hindrance, AT&T's LTE network provides a strong foundation. Constructing 5G on top of this foundation will allow AT&T to drive its mobile network to new places. One key contribution that enabled this trial was new high frequency spectrum. AT&T will leverage this type of spectrum for its 5G launch. 5G can change the way networks are sold and consumed changing the landscape in future years.

The Ericsson 5G Radio Network was a key player

To transport the data, the partners turned to Ericsson's 5G New Radio (NR) network. The 5G NR network achieves high speeds through many advancements in technology, most notably the application of massive multiple input multiple output (MIMO) antennas and Lean Design. In the U.S. Open trial, the antennas received the transmission from the Mobile Test Platform. The massive MIMO antenna generates multiple narrow beams which can be accurately pointed to the user equipment, and vice-versa. It then tracks the user equipment through beam forming and a beam tracking mechanism.

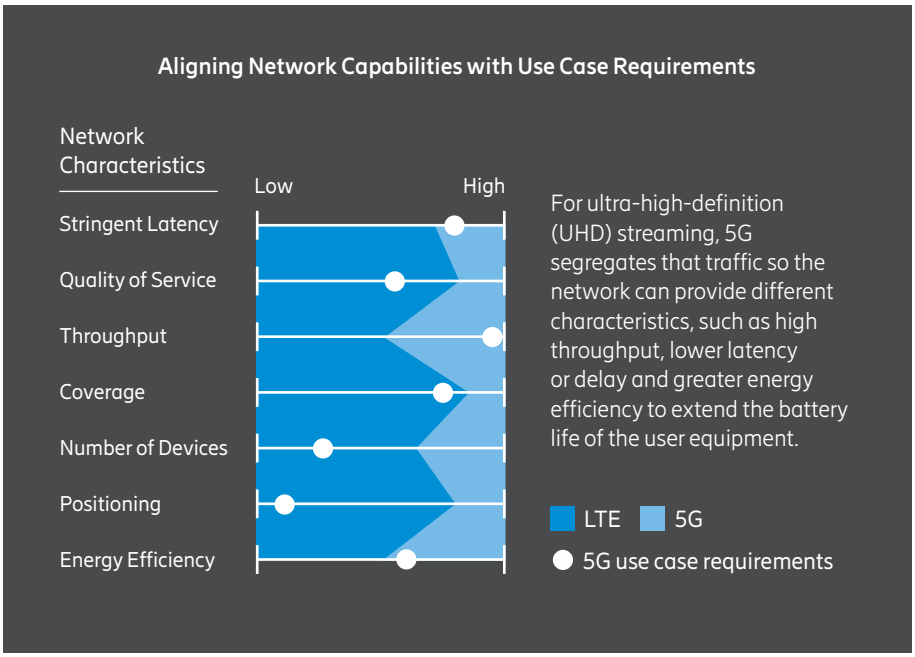
The unique characteristics of the massive MIMO and beam forming solution from Intel and Ericsson helped not only to extend the coverage but also to reduce the noise from other transmissions (similar to tuning out a conversation in a noisy restaurant), requiring less power consumption and producing higher throughput. The communication becomes more energy efficient (green), extending the battery life of user equipment while providing a more precise and reliable transmission.

The technology coupled with AT&T mmW spectrum holds the promise of handling higher amounts of data accurately, with higher throughput speeds and lower latency or delays in the establishment of transmission. In the future, as user equipment mobility increases, the narrow beams in both directions can quickly adjust, delivering reliable, superior performance.

8. Feb 2018, Ericsson analysis based on North America Speed Test Intelligence data from Ookla

5G proves itself on the course

Current 4G/LTE technology is simply unable to support the identified UHD 4K broadcast quality video streaming use case, due to the significant demands for uploading large amounts of data at very high speeds and reliability. 5G, on the other hand, is designed to handle these demanding requirements at an application level. The graph on the right is an illustration of the demanding network characteristics on each network dimension between LTE and 5G. While some use cases may require 5G for greater position accuracy or very high connection density, a use case like the U.S. Open is driven by demand for very stringent latency (real-time), very high throughput speeds and improved energy efficiency or lower power requirements to extend the life of the camera battery. The dots represent the network demands of broadcasting live 4K video. As the illustration shows, this use case's demand for stringent latency, exceptionally fast throughput and improved energy efficiency could only be delivered by a 5G network.



Requirements of broadcasting 4K video—comparison between capabilities of LTE and 5G
The above chart is an illustration of some of the network characteristics that this use case may require from the wireless network.

5G can meet the performance demands of stringent applications

Not only can 5G reliably transmit large volumes of data, it will eventually offer at scale the ability to segregate traffic on the network and deliver the particular characteristics required for the best performance for a specific application. By allowing for different service quality and priority for the important 5G video transmission, 5G could ensure that the important live broadcast is not impacted by the consumer traffic competing for the network resources during this event. In addition to the enhanced quality of service, 5G will have inherently higher data security, reducing threats from outsiders.

At the U.S. Open 2018, 5G proves a winner

The trial verified that by using 5G, AT&T, Ericsson, FOX Sports and Intel could solve many of the challenges faced at major sporting events. The introduction of 5G offers efficient network configuration options for broadcasters such as FOX Sports, thus guaranteeing the required throughput, latency, quality and reliability at lower overall production costs as the workflow of a live event is transformed. As the ecosystem of devices matures, 5G adds a large range of mobility for cameras to move freely to follow the action of a live event, and not be limited by physical fiber connections.

As video encoding and decoding technology evolve and is virtualized for high capacity UHD, the edge compute capability of the 5G network will further streamline the delivery of UHD video from live events improving efficiencies, performance and ultimately greater business value.

Part III: Key findings now and looking forward

5G transformational technology transforms business operations, too

The U.S. Open project demonstrated stable, high-throughput wireless transmissions and identified anticipated areas of value in lowering the production costs for live event coverage. During a live event, video is captured on-site and sent, traditionally, via fiber to on-site production trucks within a production compound where most of the video from the event is produced and packaged. From the production compound, the packaged video is transmitted to a centralized distribution center. This transmission is referred to as backhaul. As the workflow is redesigned using 5G, efficiencies are expected in both areas:

> Reduce production costs and improve efficiencies
  - Removing fiber from the course or "on-the-green savings"
  - Reduce the footprint of assets (people and equipment) needed at the event site

> Improving backhaul transmission costs to the distribution center

Enabling remote production

As we demonstrated in this trial, 5G is an excellent transmission method for moving very high bitrate 4K camera images from the green to the on-site production compound and indicates potential cost efficiencies.

Savings could be gained by reducing the size of on-site operations including technical staff, cabling, fiber install and de-install, antennae placements, and set-up costs. Overall, the length of time needed for set-up and tear-down would also be reduced. Analysis of the U.S. Open use case indicates a 5G cellular system can produce an anticipated minimum savings of 34% over current methods.

Furthermore, as the 5G ecosystem evolves, 5G could enable a practice of at-home production. In today's world, images are captured in camera and sent via fiber to a large-footprint production compound where they are produced before being sent to central location for distribution. At-home production allows broadcasters to reduce costs by producing and distributing shows from a centralized location reducing spend on production vehicles, satellite uplinks and travel costs. A 5G network could streamline the current process by enabling images to be sent straight from the camera to the centralized location where the video would be produced and distributed for broadcast.

Efficiencies in backhaul transmission

The performance of the 5G network indicates even larger production savings may be possible. Bandwidth for backhaul transmission is one of the largest costs for an event like the U.S. Open. Backhaul transmission refers to the process of sending the produced show (today created on-site) over satellite or fiber from the event site to the distribution facility where it is broadcast to viewers. In the case of the U.S. Open, the images were captured and produced in Southampton, NY, and transmitted to Los Angeles, CA, for distribution.

Against current pricing models, as 5G coverage and availability expands, significant savings can be expected in backhaul transmission. In this scenario, we compare bonded cellular, which is a technology that combines 3G/4G/LTE and soon 5G modems into a single internet connection often used for deploying live video. The traffic is routed to the appropriate type of service therefore creating a blended rate or cost of cellular services. Bonded cellular is then compared with two existing backhaul alternatives—domestic fiber and satellite. For this analysis, we have taken the approach to exclude potential hardware savings as market prices are still unclear, so this represents a conservative estimate of potential savings.

In the case of the U.S. Open, transmission generally occurred at 30Mbps for MPEG and 150Mbps for JPEG. At the U.S. Open, footage was captured from 5 a.m. to 8 p.m. every day over the course of four days. Our model assumes a cost of $15.00/GB as a weighted aggregated cost and a transmission time of six hours.

As the tables demonstrate, significant savings are obtained using a bonded cellular system that, when commercially available, will include 5G to provide increased capacity and speed. Note that the savings are greater at lower bit rates. An additional benefit to production could be gleaned if the workflow included hardware such as newer model HEVC encoders which could achieve a constant 10 Mbps output with the same or better picture quality than in MPEG-4.

Bonded Cellular vs. Satellite

Mbps	Transponder	% Savings
10	0.5	81%
20	0.5	61%
25	1	66%
30	1	59%

Bonded vs. Fiber

Mbps	% Savings
10	91%
20	82%
25	77%
30	73%

Source: FOX Sports

"The trial using Intel's Mobile Trial Platform showed how broadcasters like FOX Sports can build new efficiencies for live sports over 5G, reducing cabling and on-site production costs, while bringing viewers a great 4K video experience right from the featured holes on the course," said Sandra Rivera, senior vice president and general manager, Network Platforms Group, Intel.

Future 5G revenue benefits

The U.S. Open project focused on production-side cost efficiencies resulting from backhaul transmission savings and remote production. "While this was a fairly simple trial," Mike Davies, FOX Sports Senior Vice President of Technical and Field Operations pointed out, "it indicated that 5G is a technology that could drive the savings of millions of dollars over the course of a production year in terms of fiber deployment and backhaul transmission, after it is fully deployed over multiple types of sports broadcasts." Future proof of concepts should also concentrate on the potential for 5G systems to deliver new revenue-side opportunities.

The concept of remote production can be extended to small footprint camera deployments that enable the coverage of more niche, regional and local sports that are currently uneconomical. In large-scale productions, nimble camera deployments could be used to live capture alternative angles or behind-the-scenes footage that could be used in main broadcast or as a customizable option for second-screen experiences.

5G also enables new content experiences. The high bandwidth, low latency attributes of 5G could power VR 360-video camera deployments for both in-venue and at-home viewers creating a more immersive fan experience. Additionally, as a backbone to ubiquitous IOT, 5G also enables AR augmentation of an event that could supply information overlays and viewing points of the event that consumers could customize based on their preferences.

Part IV: The transformative future of 5G

In production of premium sports experiences, for both in-home viewing and on-site spectating, the complexity of delivering QoE presents a major challenge. The broadcast environment is attempting to meet increasing consumer demand not only for additional, customizable experiences such as alternative camera angles, augmented reality and a virtual 360-degree immersive experience, but also for better quality and higher resolutions, such as 4K and ultimately 8K, to make the experience life-like even in the viewer's living room.

Simultaneously, spectators at an event increasingly expect better coverage to share their experience across their social sites and to experience all the immersive fan experiences possible through enhanced mobile video.

The nature of sports production will exacerbate the strain on cellular network capacity. Sports are generally seasonal, or, like the U.S. Open, occur in different locations every year. Cellular usage and the infrastructure required to deliver this capacity is heightened during a sporting event, very different from normal usage patterns.

The U.S. Open Project was a first foray into assessing the performance and cost efficiencies of instituting 5G technology into the production workflows of a major sporting event. "From the Lab to on-location, we worked with our partners to integrate the capabilities of 5G into the workflow of a large-scale Sports production, resulting in performance learnings that inform future, more complex use cases," said Danny Kaye, Executive Vice President of 20th Century FOX and Managing Director of the Fox Innovation Lab.

The test proved 5G's viability as a solution that meets and beats technical expectations in nearly every dimension—and opens the door to new workflows and, potentially, new use cases. "In close partnership with AT&T, Intel and FOX Innovation Labs, Ericsson was proud to deliver this innovative solution using both our high-performance network and media products. This is one example of the number of ways that 5G can have a transformative impact on many different digital business models to deliver new and innovative customer experiences leveraging co-innovation through a robust partner ecosystem," concludes Ericsson's Bäckström.

It's hard to underestimate the advantages of this workflow transformation and we believe 5G promises great business value.

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About FOX Sports

FOX Sports is the umbrella entity representing 21st Century FOX's wide array of multi-platform U.S.-based sports assets. Built with brands capable of reaching more than 100 million viewers in a single weekend, FOX Sports includes ownership and interests in linear television networks, digital and mobile programming, broadband platforms, multiple web sites, joint-venture businesses and several licensing partnerships. FOX Sports includes the sports television arm of the FOX Broadcasting Company; FS1, FS2; FOX Sports Regional Networks, their affiliated regional web sites and national programming; FOX Soccer Plus; FOX Deportes and FOX College Sports. In addition, FOX Sports also encompasses FOX Sports Digital, including FOXSports.com and the FOX Sports app. Also included in the Group are FOX's interests in joint-venture businesses Big Ten Network and BTN 2Go, as well as a licensing agreement that established the FOX Sports Radio Network.

About Fox Innovation Lab

The Fox Innovation Lab is 21st Century Fox's research and development center established to drive the advancement of groundbreaking technology and new consumer experiences across all platforms and distribution models. The Lab works closely with production, marketing and distribution across all 21st Century Fox film and television divisions as well as key external partners to advance next generation technologies including HDR10+, an open, royalty-free dynamic metadata platform for High Dynamic Range; 4K Ultra HD with high dynamic range; mobile content experiences; and virtual, augmented and mixed reality, all featuring immersive audio. The Fox Innovation Lab serves as a research hub, demonstrating and testing technologies with consumers throughout the development process to obtain qualitative data and hands-on feedback in order to bring innovative and premium products to market.

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