2019

5G Mobile Edge Computing

Redefining the Sports Experience

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Introduction

We live in unprecedented times. The pace of change in technology evolution has picked up tremendously over the last few years. The coming together of some critical technology trends are enabling the possibility of a future full of promise to tackle new computing and communications problems. 5G is no longer a buzzword but a reality at the doorsteps of enterprise and consumer growth. The step change in capabilities is allowing engineers and product managers to envision new experiences to shape the human engagement. Tremendous leaps in computing power at the edge of the network are making what seemed like a herculean task, possible. Artificial Intelligence is allowing for systems to learn from data and help algorithms architect new ways to manage and route terabytes of data in real-time.

History has proven that when new capabilities are introduced into the market, entrepreneurs use the platform to create new user experiences, new products, new alliances, and new revenue streams. The current cycle of 4G network evolution has proven this multiple times. The advent of smartphones and LTE gave birth to Uber, Google and Facebook Video Advertising, as well as Alibaba and Tencent's rise as China's technology giants. The impact of 4G has been so profound that the digital ecosystem is worth much more than the 4G platform that enabled it. We expect the same will be true with 5G. In fact, the new capabilities being introduced in 5G such as Ultra Low Latency, Very High Bandwidth availability, Network Slicing, Dense IoT deployments are going to become powerful tools in the hands of developers.

Many don't realize that the nature of computing is changing itself. We go through the generational cycles of centralized and decentralized computing. We are seeing a collision in different technology growth curves that is creating unique opportunities in Edge Computing. The data demand and need for really fast processing is necessitating the desire to explore new opportunities at the edge. As a result, the role of end-nodes in how they shape the applications and services can be quite disruptive.

We can think about the new environment as distinct functions of hardware, software, and data. Each capability is modular enough to invite 3rd party developers to innovate on the underlying platform to create new use cases and revenue streams. For example, VR streaming in a stadium can put fans right in the middle of the experience. The ability to manipulate the viewing angles or follow the eyes of a specific athlete can provide unprecedented entertainment value. Furthermore, the data stream can be analyzed in real time and new forms of software and intelligence can be applied to extract knowledge which can be fed into different applications and services across different verticals. Each has its own business model and SLAs.

This paper delves into 5G Edge Computing and the use cases it enables. We will go further into discussing one such use case – Smart Venues. 5G will enable new experiences in stadiums and venues. But what does it take to pull it together? What are the application requirements going to be? What applications and services will such an infrastructure enable? How are venue owners looking at this opportunity? How can the data flows be managed and optimized?

Stadiums provide one of the most challenging operational environments – thousands of fans all connecting in real-time to content, data, and people; they want to maximize their experience while they are there, they want to minimize disruptions and have little tolerance for poor computing or network performance. There are few things that test the network like Live TV. Trying to do anything with video in real-time requires seamless cooperation between network, computing, and data resources. As such, stadiums will stretch the technology infrastructure and specifications to the limit and provide invaluable lessons. Lessons from Edge Computing in smart stadiums will also provide a blueprint for more applications and services in other industries and domains.

Edge Computing Will Transform the Enterprise

Computing goes in cycles of centralized and distributed. Mainframes that kick started the computing revolution always focused on a central, powerful computer with dumb terminals to crunch the numbers and provide raw power. This was true for most computing environments until the early nineties. The PC at every desk changed the model to a distributed one wherein computing stations and later portable PCs became powerful enough to do computing tasks in a distributed fashion. This lasted for almost two decades.

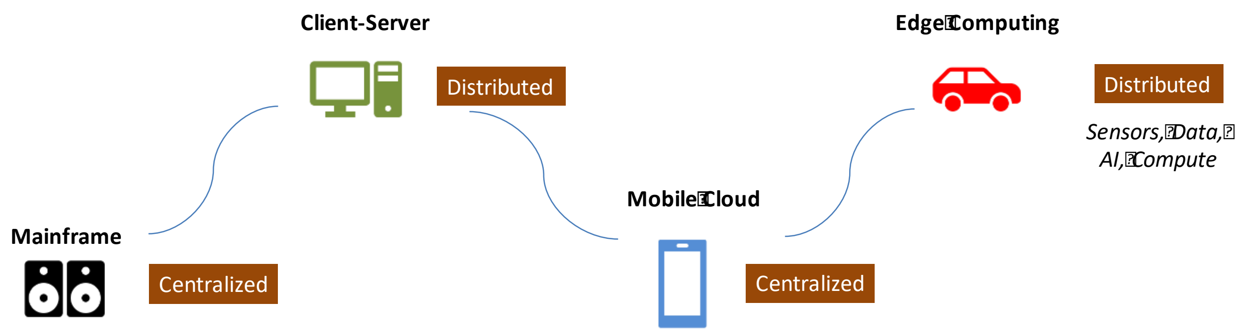

Figure 1. Computing Cycles[1]

With mobile and cloud, the cycle reverted to a centralized architecture wherein cloud formed the core nervous system for applications and services and the mobile devices at the edge focused more on the interface than computing. While we haven't fully realized the benefits of the third computing cycle completely, we are for sure entering the shift again to a more distributed, edge-centric computing model (Figure 1).

The drivers for the rise in demand for Edge Computing are many but the most critical one is that the power of a mainframe can now be found in tiny chipsets that can be embedded at the edge. Mobile broadband capability further enables fast transmission of data, but it is really the computing power at the edge that can analyze the data locally either before sending it further up the stack for processing or while sending to processing centers for longer cycle and larger scale analytics. Furthermore, data storage and AI capability at the edge, informed by the localized derivatives of central analytics further creates a powerful set of solutions unlike anything we have seen in the past.

The ability to process TBs of data and pump out actionable intelligence in a matter of ms is likely to define the next computing cycle. All of the sudden, end-nodes become computing hubs and can help unleash new capabilities in every industry. For example, each average flight generates roughly 1-2 TBs of data. Once the plane lands, it is either transmitted (which both takes a lot of time and is quite expensive) or is physically carried to the computing facility for further processing. By regulation, the entire dataset has to be transmitted for processing. But if we move the processing capability to the

[1] Source: Chetan Sharma Consulting, 2018

edge where, in a matter of seconds, the airlines and regulators could know if there are any anomalies in the data and require further action rather than wait hours for the data processing to be complete. It can shorten the maintenance windows and save costs.

Taking the notion of Edge Computing further, data can also be analyzed as it is being gathered in real-time while the airplane is in the air, so the analysis is all complete by the time the plane lands. Edge Computing clearly helps create new operating and business models for the existing supply-chain. Edge Computing will play a significant role in smart-city initiatives worldwide as computing and communications get woven into the fabric of the city.

At CES 2018, the biggest industry tradeshow, the CEO of Intel unveiled a 49-qubit quantum chip. Intel's roadmap suggests researchers could achieve 1,000 qubit systems within 5-7 years.[2] Having this computing power at the edge will transform both computing and the network evolution.

While the evolution of Edge Computing is going to lead to very interesting applications and new models for distributed data analysis, we are likely to live in a hybrid world where cloud and edge work in concert to balance the workloads for a long-time. As such, enterprises should plan to leverage both modes of deployment and take advantage of available tools to build their infrastructure stack.

Edge Computing Drivers

Edge Computing will play a significant role in defining the next computing cycle. It is driven by several factors such as the emergence of 5G as the next cellular standard that is designed for new use cases, the insatiable demand to process data at the source and be able to transmit the data in a matter of milliseconds, the competitive nature of the verticals demand new business models to take shape that allows for new discoveries and potential ways to enhance the user experience of an ever-demanding consumer, providing security of guests at all times, and managing cost and performance in a way that can scale.

Fan experience

All technology requirements start from how we can imagine the fan experience. An owner must worry about what unique and memorable set of experiences they can provide so the fans keep coming back and spend more with them. The journey starts at home wherein the app can prepopulate content based on a customer's history and preferences. As they hop into a vehicle to go to the stadium, the app can guide them to their parking spot to minimize time lost in congestion. For every minute saved outside the stadium, the chances of commerce go up inside the stadium.

[2] https://spectrum.ieee.org/tech-talk/computing/hardware/intels-49qubit-chip-aims-for-quantum-supremacy

Anyone who has been to sport stadiums prepares themselves to weather long lines and security checkups given the current climate of heightened security. If technology can aid in doing the security checks and authentication, it will speed up the entry process. Once inside the stadium, with the help of micro-location detection, the customer can be guided to their seats, suites, or the concession stands of their choice. For high-end customers who want to experience the game from suites, they have spent many thousands of dollars to make their experience a pleasant one. Again, by doing face authentication, one can reduce the number of security checks required from the gate to the suite.

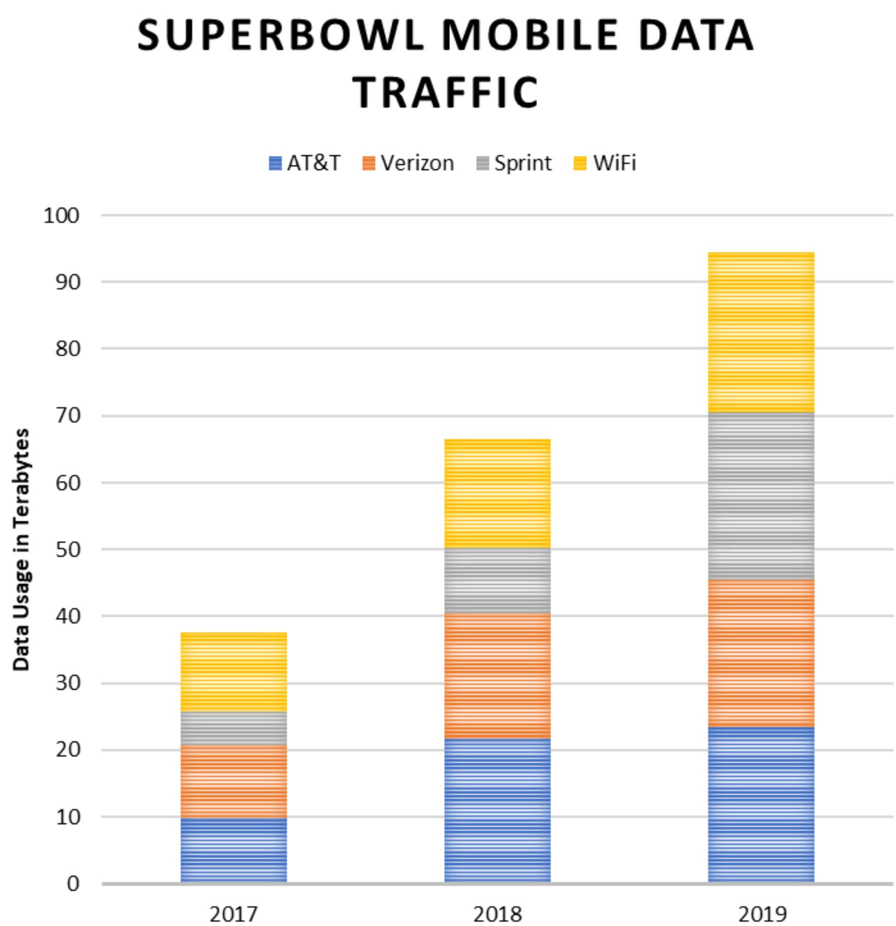

Figure 2. Superbowl mobile data traffic growth was 42%[3]

In the stadium, once the fan reaches their seat or suite, they expect to be fully connected. During 2019 Superbowl, easily the biggest sporting even in North America, the total data transferred over WiFi was 24 terabytes which was a 42% jump from 2018. Cellular network providers also report some astronomical numbers with Sprint coming out on the top at 25 terabytes for the game jumping over 158% from the previous year. Social media contributed to 55% of the WiFi traffic with streaming dominating the

[3] Source: Operators, Chetan Sharma Consulting estimates, Extreme Networks

landscape. On average 60% of the users were engaged with their devices with 65% of them at the same time.[4]

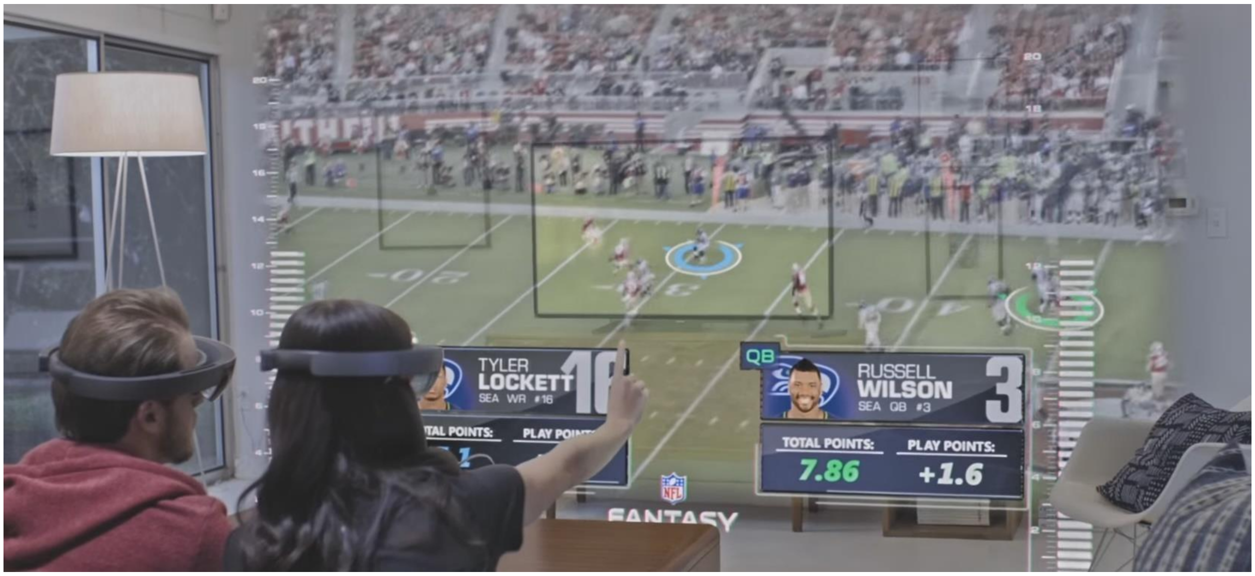

Figure 3. Expanding the field of view using mixed reality HoloLens[5]

Not every fan has a great seat or a great view. They might also miss a crucial play while they were out fetching popcorn. New technologies now allow them to essentially view any play up close and personal, replay it from different angles. Not only that, AR and VR allows the fan to essentially watch the game through the eyes of their favorite player or the referees. Having this ability to experience the game in such a deep immersive way is a sports fan's nirvana. Additionally, having the statistics in real-time at the fingertips and with each video frame is enormously valuable in understanding the game and augmenting that knowledge for bragging with their colleagues.

Scaling Computing and Communications

The stitching together of video frames in real-time on-demand from virtually any angle is an enormously difficult computing and communications challenge. The real-time feeds are coming from dozens of cameras around the stadium, these are fast moving frames, so they are transmitted at several Mbps. Add this to the dimension of simultaneous user requests, the network must scale to meet the demand in real-time. New experiences will invariably increase the demands on the network and computing resources several-fold. New technologies such as 5G and Edge Computing will be needed to help manage costs and performance.

[4] Sources: https://www.mobilesportsreport.com/2018/02/verizon-sees-18-8-tb-of-cellular-data-used-at-super-bowl-52/, https://www.extremenetworks.com/extreme-networks-blog/wi-fi-engagement-insights-from-super-bowl-lii/

[5] Source: Microsoft, https://www.youtube.com/watch?time_continue=72&v=HvYj3_VmW6I

Analytics

In addition to the raw video streams, analytics is a critical component for applications not only to understand consumer behavior, peak demands, content types, etc. but to facilitate real-time feedback into the network regarding congestion, routing, and applying AI principles to manage cost and performance. The front-end network has to interface with the backhaul, cloud, and other network types to figure out caching, Quality of Experience (QoE), Quality of Service (QoS), aggregation of access functions across different modes. Analytics feed can help in better understanding and management of data streams. They can also load-balance computational loads, power management, and help in smooth operation when it really matters.

Figure 4. Stadium applications and services[6]

Security

Given the rise in terrorism incidents, stadiums and law enforcement have to be on high alert during the entire duration of the game including hours before and after. A security breach needs to be detected and dealt with in a matter of seconds. Sensors and software can be the eyes and ears to protect the fans. In addition to physical security, one must also prepare for potential disruptions from cyberattacks that can create chaos and confusion. There are roughly 1000-2000 cameras around a stadium and each of them is capturing images and video streams that need to be processed in milliseconds.

[6] Source: Intel

Sometimes, the task is to find a needle in a haystack. Without Edge processing, the task will be difficult to accomplish.

New Business Models

The competitive intensity in every segment of the industry has forced players to seek an advantage in discovering new business models and revenue streams. Stadiums not only want to keep the seats full but also increase the commerce as well as connect with their community pre- and post-games. They want to give them exclusive and unforgettable experiences and, as such, they always looking for new technology to provide that extra advantage. The confluence of chips with some extraordinary speeds, networks that can transmit data in Tbits vs. Gbits, AI software that can forecast and reimagine experiences, devices that are more powerful than server farms, gives us new tools to experiment with business models and think of engaging consumers to create new revenue streams.

Management of Costs

There are many ways to deal with data traffic, one can increase the number of servers or allocate more bandwidth and spectrum but increasing costs to scale growth is not always desirable. The data demand of applications and services such as AR/VR experiences that requires Gbps of speeds, TBs of data, and ms of latency needs to be managed in a cost-effective way so that ROI and TCO of the initiative is acceptable and attractive to the franchises who want to stay ahead without breaking the bank.

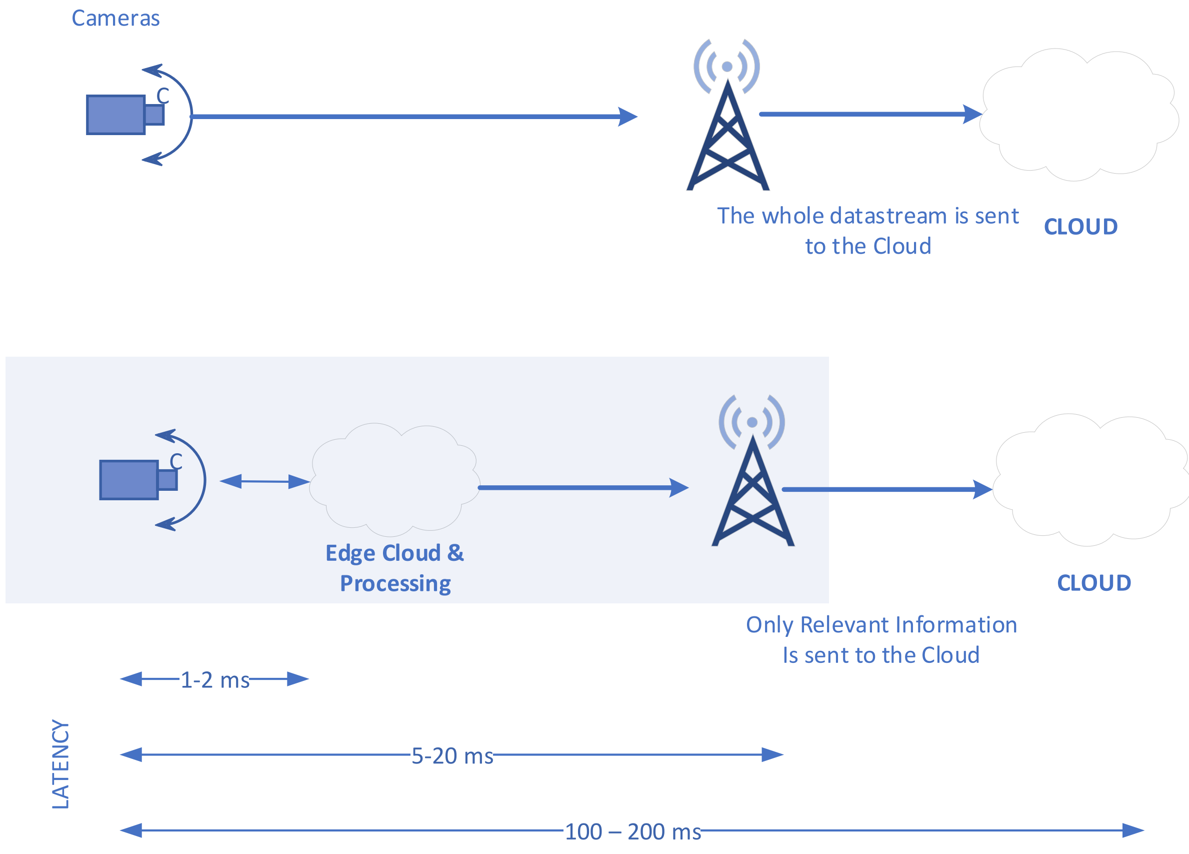

Figure 5. High-level systems diagram of Stadium Edge Computing

Sending data streams to the cloud for processing is not only going to induce several seconds of delay but it is going to be cost-prohibitive. For example, cellular traffic doubled during 2018 Superbowl compared to the one in 2017. Given that new smartphones are a step change in functionality and new network capability such as carrier aggregation and massive MIMO is going to be available in 2019, we are likely to see another step change in network demand. One can't just keep doubling the cost to manage such costs especially if they have to be replicated week after week for different sporting events.

On top of this, if we had AR/VR experiences, we are looking at exponential stress on the networking resources as such new techniques needed to better manage the load and user experience.

Management of Privacy and Security

Edge Computing helps in two major areas that are on top of policy makers – privacy of consumer data and cybersecurity. Given that Edge can keep the data and even intelligence derived from the data local, it is a desirable outcome in many jurisdictions where data residency laws have started to come into effect. So instead of sending the data to a centralized cloud in some country or location, the data can stay closer to the end-user thus reducing the chances of being compromised or being in violation of data regulations.

Similarly, an Edge node can detect and prevent a cybersecurity attack taking place more efficiently than a centralized cloud, Edge can detect tampering with resources and alert other nodes before they get compromised. They are not dependent on receiving feedback from a centralized server for further processing. The local intelligence can determine the threat and take it offline before the virus can spread through the network and disrupt service and commerce. Thus, Edge is able to handle issues around privacy leakage, data tampering, denial of service, service manipulation, man-in-the middle attacks, rogue gateway and data center attacks, and other new forms of attacks and isolate the loss or disruption.

Thus, handling cybersecurity at the Edge is more economical than the traditional cloud model.

Stadiums – Perfect Testbeds for Edge Computing

Stadiums have long been a perfect cauldron for testing new technologies and business use cases. The reasons are straight forward. There are thousands of passionate fans who want to get up in the morning and dedicate many hours of their day or weekend to sports by arriving early and getting absorbed in the game and the team they are rooting for. They want to share their experiences with friends and family outside the stadium, experience every moment of the game up close, capture and store memories, conduct frictionless commerce, avoid delays in the parking lot or at the concession stand, and look for serendipitous moments in the game.

This places strong requirements on the technology infrastructure for both computing and communications. The most recent iPhone (iPhone Xs Max) is capable of 5 teraflops which is 66 times more powerful than the iPhone released only 5 years ago. The computing power of the most pervasive edge devices has been compounding every year.

During the last Superbowl, the peak transfer rate measured by Extreme Network on their WiFi infrastructure was 13.04 Gbps.[7] The social networking engagements are specially taxing as they place severe demands on both the data and the control planes.

[7] https://investor.extremenetworks.com/news-releases/news-release-details/extreme-networks-reveals-record-breaking-wi-fi-usage-super-bowl

There was a 9% jump (2.83 TB) in social media data traffic. As such the networks need to be resilient and able to handle both throughput as well as peak capacity demands. Sports fans are also very tech savvy, always looking for new ways to absorb content and live play. New tools like AR and VR can provide fundamentally new ways to experience live sports that was just not possible before. Further, stadiums are also a great place to test technologies that can be deployed in other high-traffic locations such as airports, malls, concerts, and festivals. Applications such as instant multi-angle replays, multi-stream video broadcasts, facial recognition and high-volume commerce will become widespread.

Given the video traffic demand requirement in a sporting arena, new technologies are needed to optimize computing and communications requirements between device and RAN and device to device to find the most optimized path of a packet to be delivered to the end device with very high consistency and fidelity. The ability of a fan who might be sitting at the back seat to feel like they are courtside enhances their in-game experience manifold.

Edge will also help in facilitating new types of application such as micro-betting. In the US alone, there are over 100M fans interested in betting.[8] Betting is expected to be a $287 billion market by 2021.[9] In fact, such applications can't be brought into the market effectively without edge solutions. There are several issues that need to be resolved in milliseconds or else the bets won't be placed in time and the proposition collapses.

Stadiums through necessity will become test grounds to test out new solutions. All of this makes sports stadiums an ideal venue to test out emerging concepts and stress-test the specifications.

Growth of ESports

There is another sports category that is emerging fast that has enormous potential. Esports is the new frontier in sports and has grown into a billion-dollar business.[10] According to estimates, there will be 201 million consumers can be classified as Esports enthusiasts which is expected to grow to 297 million by 2022. The audience is highly prized millennium fans who are eager to engage with brands that appeal to their ambitions and tastes.

Esports is an entirely new genre of entertainment that mingles the passion of community watching with competitive sports. Korea pioneered the space that treats its

[8] https://www.americangaming.org/resources/sports-betting-consumer-study/

[9] Betting Dollars. Source: Deloitte's sports industry starting lineup, Trends expected to disrupt and dominate 2019, https://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/articles/sports-business-trends-disruption.html#

[10] Source: https://newzoo.com/insights/articles/newzoo-global-esports-economy-will-top-1-billion-for-the-first-time-in-2019/

players as celebrities, leagues are getting created which are being backed by serious money and investment and these competitive teams will be no different than what occurs in NBA or NHL. Games like StarCraft, League of Legends, and Overwatch have taken over the Korean eSport ecosystem.

Once we add additional experiences in AR/VR, tactile interfaces, holographic imaging, and commerce, we will be skyrocketing the popularity of Esports to a new level. Technology will play a central role in orchestrating experiences and given the volume of data involved for computing and communications, Edge will play a central role in the growth of the Esports segment over the next decade.

Figure 6. Esports Stadium Arenas[11]

In addition to entertainment and community comradery, we will see the Esports betting as a revenue stream wherein fans bet on the next move, the outcome of the games, and pretty much every nuance of the journey of the game and tournament. Each of superstar league teams will become their own empires commanding top dollars from advertisers and investors alike.

Challenges with Live Video

Engineers know that live video is the most challenging environment especially when millions of eyes are on it. Slightest of the delays is noticed and any dramatic play can tax the network at any instant. Furthermore, if the computation gets more intensive, without a new Edge architecture, it is just not possible to manage the fidelity of the

[11] https://esportsobserver.com/esports-stadium-concepts/

streams. There is a quantum jump in requirements when it goes from normal video streaming to volumetric video. There is a similar jump when computational and communications requirements move from volumetric to VR streaming. While we don't have enough data yet on holographic streaming, we can expect another order of magnitude complexity in creating holographic experiences. The traditional network architectures are not capable of handling the real-time requirements when frames need to be stitched together in micro-seconds.

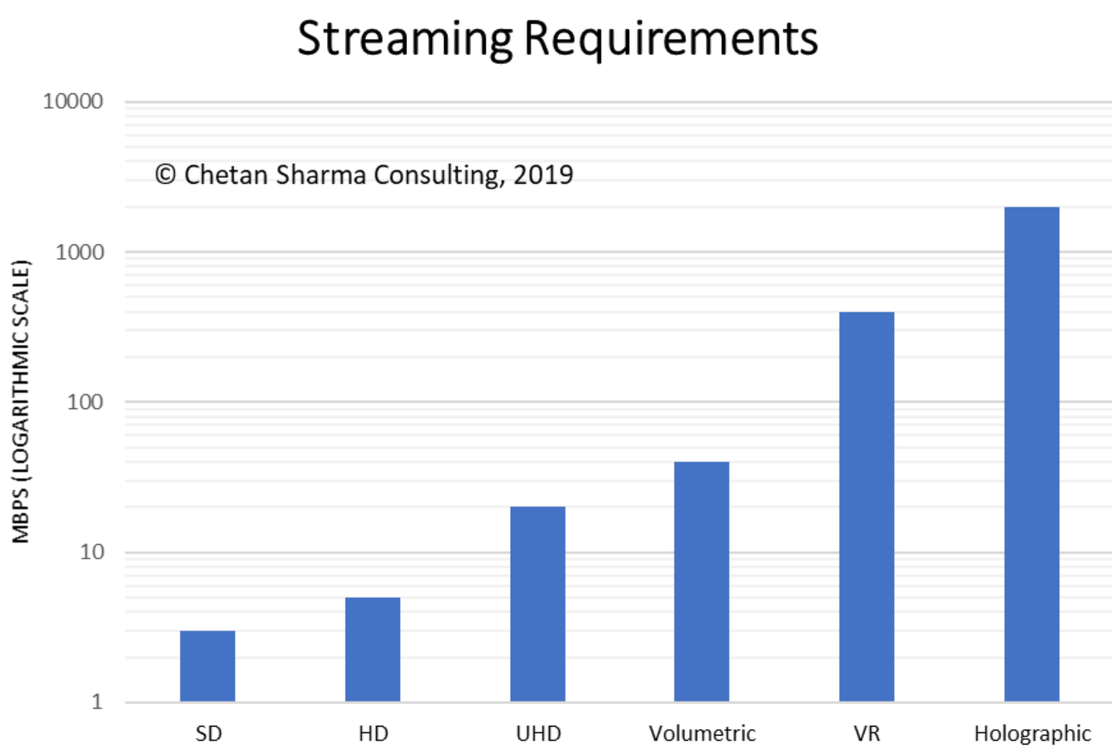

Figure 7. Streaming requirements for different forms of media streaming

Figure 7 shows how the streaming requirements increase as the complexity of the image increases. The number of streams that must be coordinated increases from 2 to 100s as you move from SD to Holographic and latency requirements increase from 100+ms to microseconds. The computational load, the I/O requirements, synchronization and image rendering become exponentially more complex with each new generation of image and video genre.

That's the primary reason for Edge to play a significant role in delivering on the promise of such services. For example, the edge processing is essential to deal with Field of View rendering of VR videos for optimization of bandwidth, latency, and battery. The stream is highly interactive, and system needs to predict user's next move and prepare the frames to deliver. Edge computing is better able to deliver the experience due to lower latency than a centralized cloud can.

Even for the most basic video streaming, Edge performs significantly better. Figure 8 shows latency for various video samples (increasing in complexity and size) if served via a cloudlet (Edge) vs. cloud. The average improvement in latency was 77%. The volumetric, VR, and holographic video are just not feasible from the centralized cloud.

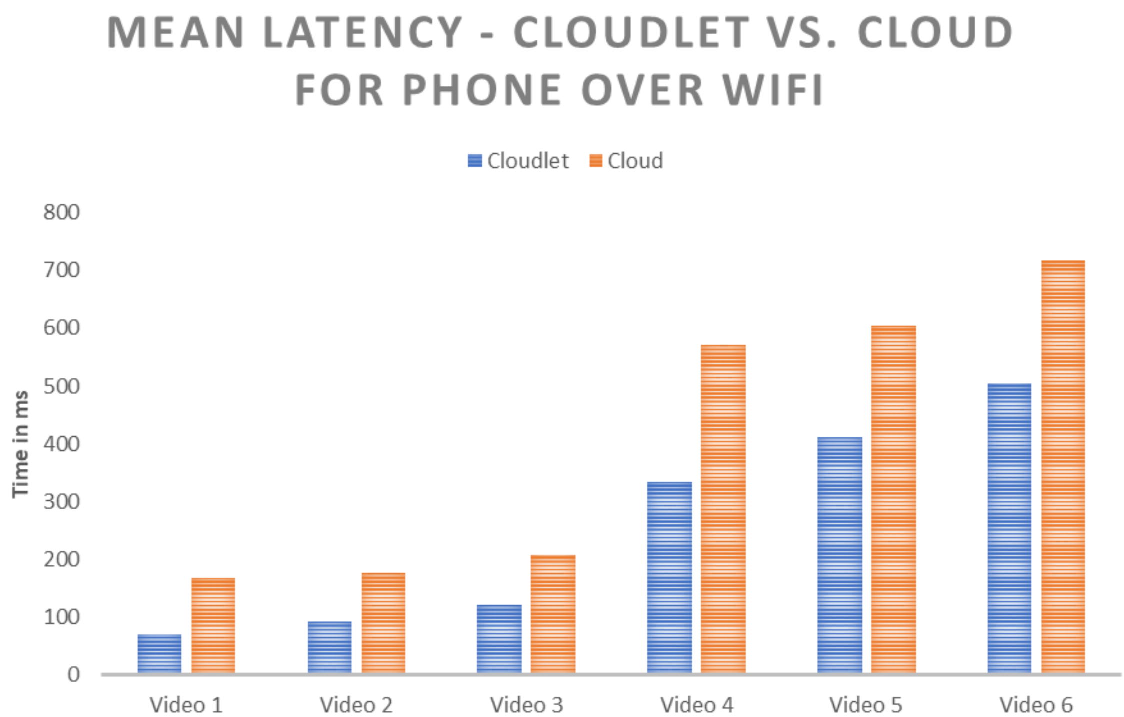

Figure 8 Latency – Edge vs. Cloud [12]

Figure 9 shows a typical sports stadium technology architecture diagram. There are some new elements that enable streaming over WiFi and/or Cellular network. The exact computational and communications requirements will depend on the nature of the streaming and workloads. For example, given the high bandwidth requirements of VR Streaming, higher bands are more suited so stadium owners might deploy a combination of private 5G over mmWave with WiFi to meet the requirements. In other cases, like Volumetric video streaming in the stadium on an app, a combination of WiFi with cellular 5G might work better given the number of end user devices.

The computational load will depend on various streaming functions like encoding, decoding, transcoding, stream capture and stitching, caching, motion prediction and rendering, load balancing, processing, and more. Where the servers are placed will depend on the overall latency requirements.

[12] An Empirical Study of Latency in an Emerging Class of Edge Computing Applications for Wearable Cognitive Assistance, Satyanarayanan et. al, Oct, 2017

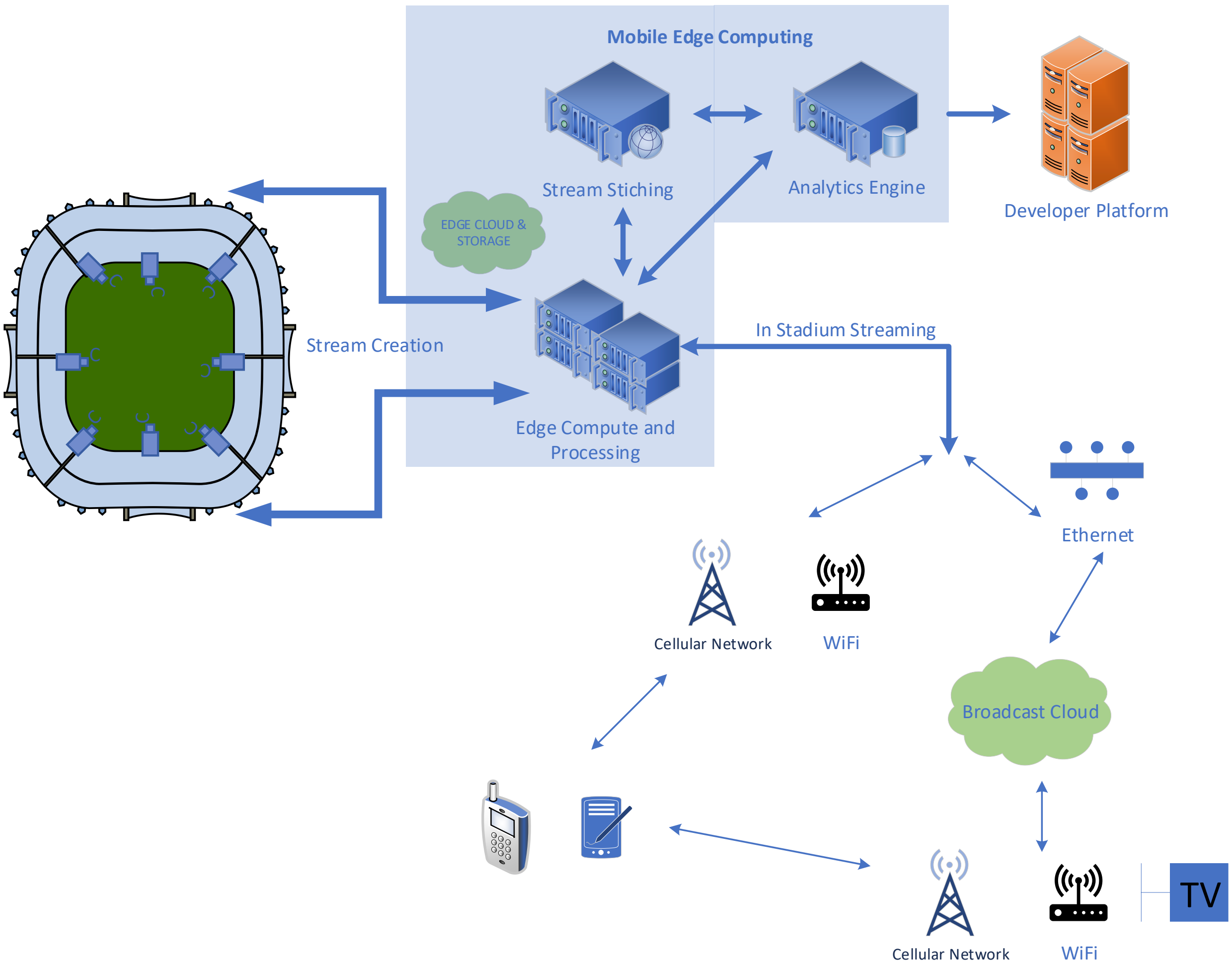

Figure 9. Sports Stadium Technology Architecture

New Applications, New Business Models

New technology generally goes for the premium experience for the premium customers. Customers who pay thousands of dollars for suites or box seats expect a white-glove treatment and new experiences to make their trip memorable. Some of the experiences such as VR, MR, and Holograms are likely to be targeted to this audience segment. The beams from the small cells can be targeted towards the suites for providing dedicated bandwidth that can carry immersive experiences in real-time. These can be 360-degree view of any play, play from a specific point or a player's eye view, or examining the future plays in detail and challenging your friends to pick the one with the highest probability.

Additionally, Edge computing can help with making the authentication process seamless requiring no human intervention. Face recognition technology at different checkpoints can help usher in regulars and suite-customers thus providing them more with their colleagues. This premium experience can be provided to others for a fee.

Furthermore, the data streams can become a platform for other developers to build applications and services on, might include enhancing of the streams to augmentation with data to social collaboration. The gamification of the live video streams to discuss, share, and store content for future use can be a huge commerce opportunity.

Edge Computing – Developer Platform for Innovation

A new paradigm in technology is only successful if it attracts enough developers to start building applications and services on top of the platform. To make Edge Computing a platform, the complexity of the disparate networks and technologies need to be abstracted from the developers using simple APIs that expose the power of Edge Computing. Once developers start to embed these APIs into their own infrastructure, applications, and services, we will see the true pickup of Edge services.

The data that is produced and analyzed could spark their own micro-ecosystems for insights and new services. The easier it is for the developers to access insights, raw data, and infrastructure attributes, the more inclined they will be to start embedding them into their apps and services. Additionally, new businesses will get created that target the fan experience and commerce. The new genres of AR/VR gaming, holographic imaging, and the layering of the virtual environment over the physical one is incredibly exciting that will lead to new experiences demanding novel tools and technologies to solve complex computing and communications problems.

Conclusions

A decade ago, the tools of LTE Broadband, smartphones, and the centralized cloud sparked a technology renaissance that created tremendous amount of new value for the ecosystem worldwide. The global economy was boosted due to new services that only existed in movies before. The confluence of 5G, Edge Computing, AR/VR, and AI are going to lead to immersive and interactive experiences that push the boundaries of how we consume entertainment and sports. These tools create new opportunities for the stadium owners to engage with the fans at a much deeper level, giving them experiences that will delight them, expand the audience base beyond the stadium, make entertainment independent of the seat position, and while doing all of that, create new streams of revenue from commerce.

The data traffic inside the stadiums is about to go to a new level. As such, new architectures inspired by Edge Computing will need to be deployed to meet the ever-increasing demands. The velocity of data creation will necessitate invention of new techniques and technologies to be applied in sports domain. This will also spur the rest of the ecosystem.

Acknowledgements

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Find more information about Intel at newsroom.intel.com and intel.com.

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