Original Research Article

# Enhancing fan engagement in a 5G stadium with AI-Based technologies and live streaming

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***Abstract:*** We participated in Taiwan's National Intercollegiate Athletic Games (NIAG) in early May 2021, and formed a Sport Technology Team of more than 30 scholars, students, and engineers to provide novel systems and solutions that make the athletic games rich in sport technologies. Some of the features could be the first time shown to the Internet audience for large-scale ath- letic games. The technologies involved include table tennis ball trajectory and bounce distribution, badminton shuttlecock track- ing and trajectory, *augmented-reality* enriched video streaming on social networks, real-time three-dimensional broadcasting with free view-angle, in-stadium video stream pushing by a private fifth-generation (5G) network with *multiaccess edge computing*, AI-based sport data analytics during live streaming, etc. All the technologies and applications are integrated in a novel *technology- enhanced broadcasting system* (TEBS) that is dedicated to sport events. This article introduces the respective technologies that we have developed, deployed, and demonstrated in the 2021 NIAG. We stress the layered architecture design and integration of the TEBS, as well as experimental results from real games in the smart stadium and swimming pool. We also discuss the technical challenges and our approaches to tackle them, as well as lessons learned.

***Keywords:*** Artificial intelligence; fan engagement; fifth-generation (5G) mobile communication; multiaccess edge; computing (MEC); operations and management; sports equipment; system of systems; video signal processing; visualization

In this article, we will introduce the technologies integrated in the TEBS, including table tennis ball trajectory and touch-down (bounce) distribution, badminton shuttlecock tracking and tra- jectory, augmented-reality (AR) enriched content for real-time video streaming on social networks, real-time three-dimensional (3-D) broadcasting with wide-field free view-angle, in-stadium video stream pushing by a private 5G network with multiaccess edge computing (MEC), real-time AI-based sport data analytics, etc. We will also discuss the design and integration of the TEBS, and show the experimental results from large-scale athletic games in the smart stadiums that we have established, i.e., the 2021 NIAG, Taiwan[14]. The end-to-end (E2E) latency in the 5G stadium is shown to be less than 30 ms as measured in the drone racing game. Note that we have demonstrated, the first time, the technologies in an integrated system, i.e., the TEBS, with live streaming to the viewers on social networks and on top of a private 5G network. In Taiwan, thanks to the efforts of the government and the entire society, the pandemic was contained to a level that we could hold the 2021 National Intercollegiate Athletic Games (NIAG 2021) in early May[14]. For exploring and expanding fan engagement, we decided to develop a system of systems for fan engagement in sport events. We then integrated the novel systems and solutions into a technology-enhanced broadcasting system (TEBS), as a system of systems, and showcased it in the 2021 NIAG[14].

## 1. Introduction

N THE past few years, even during the COVID-19 pandemic, the sports industry has been busy introducing

high-tech solutions into stadiums, arenas, fields, domes, parks, education, and training facilities in many parts of the world[1-5]. In addition to the fifth-generation (5G) mobile communication, the engagement of AI-based data analytics and the *Internet of Things* (IoT) in sports also is triggering growing demand for advanced sensor technologies, e.g., microchip Doppler radar, high-speed and high-resolution cameras, camera arrays backed by video stitching/fusion, wearable devices, and RF-ID tags and sensors that monitor athletes and other moving objects in the games[6-13]. The huge amount of data generated by all the sensors during training or in the games will need to be processed online and/or offline. For that reason, AI-enhanced data analytics seem inevitable[6]. The technology trends for sports are becoming clear—fan engagement, smart stadium, im- mersive media, quantified athlete, next-generation sponsorship, e-sport, etc. Among them, *fan engagement* has been under the spotlight recently as fans represent the most significant part in the sports industry value chain. As a result, almost all major 5G players and cloud/AI companies had planned to showcase their products and services in the 2020 Tokyo Olympics[6], though unfortunately as we have already witnessed, most of the plans had been negatively affected by the COVID-19 pandemic.

## 2. 5G stadium with AI-based sport technologies

The integrated applications in the TEBS is depicted in **Figure 1**, which shows the main application systems deployed on top of the 5G network, including 1) object tracking and trajectory (covering table tennis ball trajectory and bounce distribution, and badminton shuttlecock tracking and trajectory), 2) AI-based swimmer tracking with AR, 3) AR-enriched content streaming, and 4) free-view realtime 3-D broadcasting. For real-time social- network streaming of sport games, we also have developed the 5G MEC-based in-stadium video streaming system. We will discuss all the components in detail, beginning with the private 5G network.

*A. NCKU Private 5G Network*

The National Cheng Kung University (NCKU) Private 5G Network located in the NCKU Stadium was built in early 2021 by Chunghwa Telecom (CHT) Co., Ltd. and NCKU, which consists of a set of next generation NodeB base stations that are connected to the MEC servers and routers via the CHT radio access network (RAN) and on-campus backhaul fibers, as depicted in **Figure 2(a)**. The deployed network devices are compliant with the 3GPP 5G NR Release-15 nonstand-alone

(NSA) specifications, including the E2E network architecture, massive antenna array, MEC, and vertical application systems developed at NCKU that reside on the firewall protected APP servers. Advanced features, including the enhanced mobile broadband and ultra-reliable low latency communications, are implemented and supported by the settings in the 5G stadium. A photo of the 5G stadium highlighting the RAN part is shown in **Figure 2(b)**, where we can see the mounted 5G active antenna system and the 4G remote radio unit.

*B. Technical Challenges of the TEBS*

The integrated TEBS provides in-stadium spectators as well as internet viewers (online fans) with exciting new experiences. As the NIAG 2021 has attracted top athletes from all over Taiwan,

In the 5G private-network business, the key success factors would not simply be higher bandwidth and shorter latency, but also the ecosystem and the provision of customized services in specific domains that 4G cannot easily achieve. In recent years, the 5G technology and applications have been show- cased at major international information and communication exhibitions, where global trends in mainstream technological applications are mostly focused on business to consumer audio- visual entertainment and business to business electronic com- merce private-network applications[15]. Today, the 5G devel- opments are no longer oriented

toward technological research, but toward applications associated with AR and virtual reality, streaming of 4K ultra-HD video and audio, etc.[16]. We have observed that justification of the value of 5G is a complicated and tedious collaboration task, which will have to be jointly demonstrated by the 5G network operators, stadium (private 5G network) owner, vertical application developers, equipment suppliers, commercial software providers, system architects and integrators, as well as service providers. Most important of all, we must ensure that all stakeholders benefit from the integrated task, which mainly lies in the high potential of business op- portunities from fan engagement. For that purpose, we propose the TEBS for fan engagement in sport events, as shown in **Figure 3**.

*C. In-Stadium Video Pushing by a Private 5G Network With Multiaccess Edge Computing*

The selected NIAG 2021 sport events were broadcasted with the help from CHT, which provides the NSA-compliant 5G pri- vate network, together with our MEC servers that are installed on campus. The MEC servers are responsible for cloud datacenter offloading as well as latency reduction of the 5G services that support the TEBS applications. To perform packet processing and traffic aggregation closer to the network edge, e.g., they analyze the user packet destination to determine the service lo- cation and direct local traffic to the dedicated user plane function (UPF) for offloading, i.e., to ensure that local broadcasting data will be handled on campus. Locally processing the data also helps to meet the 5G low-latency specifications. From Fig. 4, we can see that in the NCKU private 5G network, the MEC servers are also connected to the CHT core network, which implements the 5G control and user plane separation architecture that allows the session management functions (SMFs) to be decoupled from the UPFs. As the UPFs are deployed on the MEC servers, they are close to the 5G mobile users, i.e., the onsite spectators for NIAG 2021 sport events. The SMFs that handle the control plane, on the other hand, are deployed at the core network to manage other UPFs for traffic routing.

Object detection and tracking is a key technology in com- puter vision. For both table tennis and badminton games, we have adopted the state-of-the-art object detection AI model, i.e., YOLOv4[17], to improve object detection accuracy based on convolutional neural network models. In the following, we will give an overview of the adopted technical schemes and address the main challenges and refinements when applying those to our target applications. More detailed information will be described in Sections III-B–E.

In the badminton games, we use YOLOv4 to track the move- ment of badminton shuttlecock and the players as well. To detect the small and fast-moving object, we have added the context attention[19] and the residual attention modules[20] to YOLOv4, as shown in **Figure 5**.

The context and residual attention modules that we propose for the modified YOLOv4 can detect and track the players and the shuttlecock simultaneously. With the residual attention mod- ule, the network can retrieve the high-level information that helps semantic understanding, so we can focus on detecting small objects. Experimental results show that the mean average preci- sion of small object detection is improved by 18% as compared with the original YOLOv4, including the badminton shuttlecock and rackets. After a series of detection and tracking, we then use a postprocessor to overlap the shuttlecocks and the player positions to draw their trajectories. Both trajectories and player positions are exhibited by AR, i.e., merged with the original image, providing exciting new information and intelligence that improves the audience's experience when watching the game online. It also helps a lot for the live broadcasters, anchors, and commentators to deliver colorful and interesting messages to the fans during live streaming.

## 3. Conclusion

We have introduced the TEBS for enhancing fan engage- ment and the NCKU 5G smart stadium that houses a private 5G network and showcases the TEBS. The TEBS contains a series of *application systems* that demonstrate AI-based sports technologies, for which we put together all sorts of commercial systems to enable live 4K video streaming on top of the 5G net- work. The entire system of systems, i.e., the hardware/network structure is depicted in Fig. 1, and the TEBS is shown in Fig. 3. The technologies integrated include table tennis ball trajectory and touch-down (bounce) distribution, badminton shuttlecock tracking and trajectory, AR-enriched content for real-time video streaming on social networks, real-time 3-D broadcasting with wide-field free view-angle, in-stadium video stream pushing by private 5G network with MEC, AI-based sport data analytics, etc. The tech-enhanced events are streamed to the social networks, e.g., Facebook, YouTube, and CHT Hami Video.

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