Application Practice of 8K Ultra-High-Definition Television at the Beijing Winter Olympics (Post-print)

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Abstract

Guided by the objective of "Tech Winter Olympics, Watching the Olympics in 8K", China Media Group, leveraging the State Key Laboratory of Ultra-High-Definition Audio-Video Production, Broadcasting and Presentation, conducted technological innovations across the entire chain of 8K UHD TV production, broadcasting, transmission, and presentation. Prior to the opening of the Beijing Winter Olympics, a brand-new 8K UHD TV technology system was constructed, and the CCTV-8K channel was officially launched on January 24, 2022, achieving for the first time globally the delivery of the CCTV-8K channel to home networks and the "Hundred Cities, Thousand Screens" 8K public large-screen broadcast. This paper provides a detailed analysis of the application practices of 8K UHD television at the Beijing Winter Olympics.

Full Text

8K Ultra-High-Definition Television: Application Practice at the Beijing Winter Olympics

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Abstract: In alignment with the "Tech Winter Olympics, Watch the Games in 8K" objective, China Media Group (CMG), leveraging the State Key Laboratory of UHD Audio-Video Production and Presentation, conducted technological innovation across the entire 8K UHD television chain—including production, broadcasting, transmission, and presentation. Prior to the Beijing Winter Olympics opening, CMG completed construction of a brand-new 8K UHD television technical system and officially launched the CCTV-8K channel on January 24, 2022, achieving the world' s first integration of CCTV-8K channel into home

networks and large-scale public screen broadcasting through the "Hundred Cities Thousand Screens" initiative.

This paper provides a detailed analysis of 8K UHD television application practice at the Beijing Winter Olympics.

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China Media Group (hereinafter referred to as CMG) employed the most advanced 8K UHD production technologies and innovative 8K UHD television transmission methods to perfectly present the unparalleled splendor of the Beijing Winter Olympics, fully interpreting the Olympic spirit of "Faster, Higher, Stronger—Together" and delivering a spectacular and exceptional Games to the world. The 8K UHD television live broadcast and replay coverage of the opening/closing ceremonies and key events represented the first large-scale 8K UHD television technology application globally, pioneering 8K UHD television broadcasting for major sporting events and earning high praise from the International Olympic Committee and Olympic Broadcasting Services (OBS). OBS CEO Yiannis Exarchos noted: "With CMG' s support, we also utilized 8K technology—this is the future of broadcasting."

A total of 16 signals participated in 8K program production at the opening/closing ceremonies site, including seven wired 8K UHD channel cameras (six positions inside the National Stadium and one scenic position on the TVS (outdoor studio) rooftop), six 4K signals and two 4K insert signals provided by OBS, plus one HD subtitle signal—all up-converted to 8K for program production. The OB van' s primary and backup chains were both IP stream signals: the main production switcher signal and the backup IP gateway switcher signal were transmitted uncompressed via primary/backup optical fibers to the master control room. The opening/closing ceremony 8K public signal broadcasting system workflow is shown in Figure 1 [Figure 1: see original paper].

1. CMG 8K UHD Television Public Signal Production

CMG collaborated deeply with OBS, adopting the world' s highest 8K technical standards. The newly built Grade A 4K/8K UHD OB van (A6) undertook 8K public signal production for the opening/closing ceremonies, while

two large-scale 4K/8K UHD flyaway EFP systems covered speed skating and freestyle/snowboard big air events.

The Beijing Winter Olympics 8K public signal production broke the long-standing technical monopoly of foreign teams in Winter Games broadcasting, representing important practice in participating in international media market competition and cooperation, while demonstrating CMG' s world-leading UHD technical capabilities and marking a milestone in global 8K UHD industry development.

1.1 Opening and Closing Ceremonies

On the evening of February 4, 2022, at 8:00 PM, the highly anticipated 24th Winter Olympic Games opening ceremony was grandly held at the National Stadium. On February 20, the Beijing Winter Olympics concluded, allowing the world to once again witness "Chinese romance."

At OBS' s invitation, CMG' s newly commissioned UHD A6 OB van undertook 8K public signal production for the opening/closing ceremonies, broadcasting 8K signals to media organizations worldwide. The UHD-A6 OB van employs a full IP architecture using the latest professional international SMPTE ST 2110-20/30 standard for IP transmission of audio-video signals. The van' s audio console uses primary and backup mixers alongside imported Sony 8K cameras for program production, perfectly completing the 8K live broadcast mission. Its richly detailed and magnificent visual effects earned acclaim from international television peers including OBS and NHK.

Among the 8K cameras on site, CMG' s domestically co-developed 8K UHD portable ENG camera was used for the first time as an outdoor position (see Figure 2 [Figure 2: see original paper]). This camera employs a 35mm full-frame 8K CMOS image sensor, supports BT.2020 wide color gamut and HLG curve per current broadcasting standards, and uses 4$\times$12G baseband output for perfect compatibility with 8K broadcasting systems. As the Bird' s Nest outdoor camera, the domestic 8K camera' s compact size and convenient setup made it ideal for scenic and fireworks shots.

To ensure high-quality 8K production, CMG' s technical team entered closed-loop management on January 21, strictly implementing the Beijing Winter Olympics overall technical plan requirements, comprehensively fulfilling safety broadcasting and cybersecurity requirements, and conducting full-scale broadcast system equipment installation and technical debugging. The team collaborated across all production departments to actively coordinate with OBS, systematically conducting power-on tests, primary/backup 8K broadcast system video/audio signal transmission tests, OBS Technical Operations Center (TOC) scheduled signal routing and content confirmation, subtitle signal interfacing, camera parameter matching and adjustment, and a series of other technical tests. Three full-dress rehearsals were completed on January 27, January 30, and February 2.

1.2 "Ice Ribbon" Speed Skating

The speed skating competition venue was the National Speed Skating Oval "Ice Ribbon," where speed skating events comprised 10 disciplines generating 14 gold medals—the single venue producing the most gold medals at the Beijing Winter Olympics. The speed skating 8K broadcasting system began equipment installation on January 28 and operated for 15 days from February 5 to 19, broadcasting all speed skating events.

The speed skating 8K broadcasting plan and scheme were finalized at the last moment through coordination with OBS and the Beijing Organizing Committee. Due to time constraints, the system machine room could only be built in the original waste clearance center. Through CMG team coordination efforts, the speed skating 8K broadcasting system successfully conducted the first 8K live broadcast among all 8K event broadcasts on February 5.

The speed skating 8K public signal production used six 8K channel cameras (see Figure 3 [Figure 3: see original paper]), with cameras 5 and 6 employing domestically co-developed 8K UHD broadcast-grade EFP cameras (see Figure 4 [Figure 4: see original paper]). These cameras, entirely developed by CMG in partnership with domestic manufacturers using domestically produced components, meet 8K international standards in technical specifications and parameters. At the competition site, the domestic 8K cameras delivered outstanding performance.

In addition to conventional cameras, specialty equipment including "Cheetah" high-speed rail cameras, cone cameras, "fishing rod" cameras, and cable-suspended cameras were integrated into the production system. Simultaneously, OBS-provided HD subtitle packaging signals, 4K signals, internal 8K IP signals, and 8K baseband signals in multiple formats required unified processing including up-conversion, 2SI-SQD conversion, and baseband-IP conversion, with careful calibration of color performance and brightness control across all signal types to present uniformly high-quality images.

During 15 days of broadcasting, the speed skating 8K system live-streamed 25 exciting events, providing audiences with ultra-high-resolution, wide-color-gamut, and visually stunning competition viewing experiences.

1.3 Freestyle Skiing/Snowboard Big Air

Freestyle skiing big air and snowboard big air events were held at the Shougang Big Air venue in Shijingshan. A total of 13 signals participated in program production: six wired 8K UHD channel cameras, two 8K slow-motion insert signals, one AI time-slicing system signal, and four 4K external signals provided by OBS—all converted to IP streams via 12G optical transmission and conversion gateways before up-conversion to 8K for production (see Figure 5 [Figure 5: see original paper]).

The big air 8K system applied for the first time CMG' s domestically developed

8K UHD IP clean-switching switch as the emergency switching system for the ski big air broadcast. This system represents the world' s first switch-based 8K UHD video clean-switching system, supporting clean switching of multiple video formats and ultra-high-definition 4K/8K multi-resolution with seamless conversion, end-to-end switching latency within one frame, and output images without frame corruption, black screens, or stuttering.

To present more accurate big air technical analysis visuals for audiences, CMG independently developed a UHD AI time-slicing system that precisely reconstructs ski jump athletes' technical movements in real time (see Figure 6 [Figure 6: see original paper]). Based on 4K/8K ultra-high-resolution video signals, this system employs artificial intelligence deep learning algorithms combined with persistence of vision technology, graphics, image processing, and automated control technology to form an AI image processing system. It rapidly separates athletes' technical movements from video backgrounds in real time, achieving "time-slicing"data visualization effects through data analysis and secondary packaging. The system completes technical movement extraction computation and time-slicing packaging rendering in just 15 seconds, fully meeting real-time television broadcasting requirements.

Due to extremely cold climate conditions and cameras and microphones distributed throughout the venue, equipment installation and technical support faced significant challenges. To ensure normal broadcast equipment operation in extreme cold, the technical team customized cold-weather protective gear for equipment, guaranteeing normal camera and lens function at low temperatures.

2. CMG 8K UHD Signal Exchange and Program Packaging/Editing Production

CMG constructed a full IP television signal exchange and scheduling system at its Fuxing Road headquarters, deployed an 8K packaging broadcast system at the Capital Gymnasium, built an 8K packaging broadcast studio at Fuxing Road, and adapted 8K editing production at Guanghua Road—providing complete end-to-end system support for 8K UHD signal exchange and program production. CMG' s 8K Winter Olympics live broadcast exceeded 100 hours, with total program duration surpassing 200 hours.

2.1 Winter Olympics 8K IP Signal Scheduling and Exchange System

CMG independently developed a full IP television signal exchange and scheduling system using Huawei NE8000-X8 series routers as core switching equipment, completed and commissioned in January 2022. This system significantly enhanced CMG' s efficient, high-quality, and convenient interactive capabilities in field transmission, signal access, and signal production.

The system complies with SMPTE ST 2110 and 2022-7 standards, follows CMG' s 8K UHD television program production and broadcasting specifications, and

fully implements uncompressed high-bandwidth IP transmission across production and broadcasting systems. It completes signal transmission tasks for CMG' s 8K broadcast signals between the Guanghua Road headquarters, Beijing Hotel non-rights-holding broadcaster press center, and Winter Olympics IBC (International Broadcast Center) area. During the Beijing Winter Olympics, the system operated stably, successfully completing 8K signal transmission and distribution tasks.

This system employs full IP transmission technology, breaking down transmission barriers between traditional production and broadcasting systems to form a network-wide signal scheduling and distribution system across the entire organization and domains. Within the signal scheduling and exchange network, physical slicing methods enable mixed transmission of UHD, HD video, audio, PTP synchronization, and control signals, achieving all-media integrated signal scheduling and distribution across the network. Simultaneously, the system introduces an SDN architecture, using self-developed media production network IP routing and switching equipment based on domestic NP chips and independently developed SDN control, management, and monitoring software to achieve cross-domain and cross-system IP interconnection. The system employs precise scheduling flow table control, non-blocking scheduling, multicast NAT (multicast address translation), dynamic resource occupancy prediction technology, and customizable fine-grained operational policy technology to achieve manageable, controllable, and monitorable signals throughout the entire system and workflow.

This represents the world' s first 8K/4K/HD full IP television signal exchange and scheduling system, as well as CMG' s first domestically produced television signal exchange and scheduling system since its establishment. It fills a critical gap in China' s UHD television production and broadcasting equipment sector, marking a major breakthrough for China in global UHD television equipment manufacturing.

2.2 Figure Skating and Short Track Speed Skating Packaging Broadcast System

Short track speed skating and figure skating events were held at the Capital Gymnasium. The 8K public signal was produced by NHK (Japan Broadcasting Corporation), while CMG' s technical team deployed an 8K OB van (provided by Beijing UHD Collaborative Center) to complete 8K program packaging and PGM signal production. This approach performed subtitle and slow-motion highlight replay operations on the basis of NHK' s 8K public signal to complete program packaging and produce the final PGM signal, using 8K and other new technological carriers to present Chinese athletes' outstanding performances.

Two 8K channel cameras were deployed on-site with two 8K wide-angle lenses. The system received two external signals (primary and backup) of 8K dirty PGM from the TOC. To avoid 8K signal quality loss, 8K optical signal transmission

and photoelectric conversion equipment were deployed in NHK' s EFP machine room to convert 4$×$12G baseband signals to optical signals for transmission to the TOC and ultimately to the OB van' s optical receiver. Since NHK' s signals were 59.94p, motion shots would exhibit smearing in a 50p system, so a frame rate conversion device with motion compensation was specially employed to effectively reduce stuttering delay in motion shots in the final program signal and improve picture quality. Slow-motion replay also employed domestically produced native 8K slow-motion replay equipment, which excellently completed real-time slow-motion and post-match highlight playback tasks during competitions.

Due to limited fiber optic resources at the Capital Gymnasium, JPEG XS compression encoding was used for lightweight compression of 8K signals to reduce video stream bandwidth occupancy. Video signals were encoded and compressed into XS streams, while audio signals were uncompressed and re-encapsulated into SMPTE 2110-30 audio IP streams. Primary and backup IP streams were output via fiber optic to front-end master control routers and signal aggregation equipment, transmitted back to CMG' s television master control 8K/4K/HD IP signal exchange and scheduling system through the TOC to provide signals for CCTV-8K channel packaging broadcast studios.

2.3 Winter Olympics 8K Editing and Production System

To complete various types of 8K Winter Olympics program production, CMG adapted the network broadcasting system' s classic workflow—including ingest, storage, editing, compositing, transmission, and archiving—for 8K. The system was interfaced and debugged with upstream and downstream systems including program production systems, internal review systems, UQC systems, media asset systems, and broadcasting systems, regularizing the 8K program production workflow and providing adequate technical preparation for this Winter Olympics' 8K program production.

The Winter Olympics 8K editing and production 全流程 employed JPEG XS encoding at 2Gbps bitrate, MXF encapsulation, and 16-track audio. Compared to 4×XAVC encoding, this offers advantages of low latency and low computational complexity at equivalent viewing quality. Additionally, JPEG XS uses only one physical file per video segment, reducing complexity in material file storage, transmission, and management while improving ingest and editing stability and reliability.

The 8K editing and production system' s 8K material sources came from two primary channels: First, a 2-channel 8K ingest system deployed at CMG' s Fuxing Road headquarters broadcast studio transmitted directly to the core storage system via dedicated lines to the Guanghua Road headquarters. Second, the front-end IBC mobile field system synchronized five channels of 8K recorded materials through file synchronization servers via 40G dedicated front-backhaul lines to the Guanghua Road storage pool. Multi-channel ingest signal support

ensured complete competition content and provided editors with more material selection options.

The Winter Olympics-related 8K production tasks totaled 82 items, allocated across two 8K columns: "Top Events" (62 production tasks) and "8K UHD Vientiane" (20 tasks, including nine Chinese team gold medal ceremonies). During the Beijing Winter Olympics, production corresponded to daily competition content with corresponding program codes. Using ingested 8K competition footage and on-site audio combined with 4K commentary audio, event replay programs were produced. For ceremony production, ENG-shot 8K single-camera materials were transferred from the front-end system to the back-end storage pool for uploading and editing.

CMG' s front-end backhauled approximately 262 hours of 8K materials to the headquarters UHD production system during the Beijing Winter Olympics, with total Winter Olympics live broadcast and recorded program duration exceeding 200 hours.

3. Innovative 8K UHD Television Distribution System

On January 26, 2022, CMG officially launched the CCTV-8K UHD television channel. CCTV-8K signals were delivered through China' s cable television backbone network to Beijing Gehua Cable TV and Guangdong Cable TV networks, providing home users with 8K UHD television services. Simultaneously, to enable more people to watch the Winter Olympics in 8K, CMG launched the "Hundred Cities Thousand Screens" promotion campaign, broadcasting CCTV-8K signals simultaneously on over 120 8K large screens nationwide, allowing the masses to truly see the exquisitely detailed and brilliantly colorful Beijing Winter Olympics.

3.1 8K UHD Television Channel Broadcasting

CCTV-8K, the world's first network-broadcast comprehensive 8K UHD channel, currently broadcasts 16 hours daily. The channel' s primary content includes documentaries, sports, and arts programming in UHD, while also undertaking UHD signal broadcasting for major domestic and international events and competitions. During the 2022 Beijing Winter Olympics, total broadcast duration reached 451 hours, including 95 hours of live coverage of opening/closing ceremonies, short track speed skating, figure skating, speed skating, freestyle skiing big air, and snowboard big air, plus 356 hours of recorded Winter Olympics programs including edited events and award ceremonies.

The newly built 8K UHD television broadcasting system employs a full IP architecture with capacity for one main channel, one personalized channel (to be expanded to 10 personalized channels by end-2022), and one virtual channel. The system' s establishment promoted implementation of 8K UHD technical standards, overcame challenges in high-frame-rate precision control and IP signal

scheduling/monitoring, and achieved localization of core equipment and system software.

The 8K UHD program broadcasting platform supports both 8K UHD file playback and 8K UHD signal live broadcasting, with multi-channel parallel broadcasting capability to support personalized broadcasting in multiple locations. The platform comprises business application service systems, IT support systems, and audio-video support systems.

The broadcasting business application service system includes broadcast scheduling, broadcast preparation, and broadcast control applications, enabling automated 8K UHD program file preparation workflows according to broadcast orders. It provides automated control over file decoding and broadcasting, signal switching, and graphic packaging overlay for 8K UHD broadcast video servers, completing scheduling control of audio-video signal systems.

The broadcasting IT infrastructure platform primarily consists of storage, servers, workstations, virtualization platforms, security equipment, and basic network modules. The broadcasting system information security was constructed according to relevant protection level requirements, implementing controls in boundary security, network security, host security, application security, and data security to ensure stable operation in a secure and trusted environment.

The broadcasting audio-video support system provides external signal normalization processing, broadcast file decoding and playback, signal technical monitoring, and system centralized monitoring capabilities. The system is equipped with end-stage switching devices for emergency signal switching and unified precision time reference. The system supports IP-based broadcasting with real-time 8K UHD television signal capability, delivering encoded TS/IP program streams to downstream users after scheduling through the 8K UHD television IP integrated distribution platform.

3.2 8K UHD Television IP Integrated Distribution System

The 8K UHD television IP integrated distribution platform provides personalized 8K UHD television program distribution for public 8K large screens and decoder terminals at screen ends. The platform is entirely based on domestically developed software and hardware, achieving distribution scheduling of 8K main channel signals and personalized channel signals at the central end, and terminal management and data collection at the edge end. The 8K UHD television IP integrated distribution platform supports scheduling and distribution of 8K AVS3 program streams, enabling personalized distribution of 8K UHD television programs across provinces and decoding playback at large screen ends, with video encoding bitrate of 120Mbps.

The program stream scheduling system provides IP-based primary and backup links with emergency selection and switching capabilities. Program stream

monitoring and listening can perform stream analysis and alarm on all program stream signals in the media scheduling matrix. After scheduling, program streams are transmitted and distributed via operator fiber optic dedicated lines. Operators providing fiber optic dedicated line transmission services are responsible for daily operation and maintenance of these lines to ensure end-to-end signal security.

Professional decoder terminals support dual-channel 8K IP stream access. They automatically switch to backup output when primary video stream interruption is detected, and output locally stored test patterns when both primary and backup video streams are interrupted simultaneously. Decoder terminals are primarily used to connect outdoor and indoor 8K large screens or 8K television displays. They support real-time transmission of operational data, security authentication information, stream monitoring data, and frame-captured images back to the integrated management and control system via operator dedicated lines.

The integrated management and control system completes data interaction with professional decoder terminals and aggregated monitoring display of the system. By binding IP addresses with professional decoder terminal MAC addresses, controllable authorization of decoder terminals is achieved. The system features frame-capture comparison functionality, comparing returned frame-captured images with platform output signal frame-captured images to ensure broadcast content consistency. The system also provides centralized monitoring capabilities, enabling intelligent operations and maintenance management through human-machine interaction based on platform policies and big data analysis.

3.3 8K AVS3 UHD Television Encoding System

The 8K UHD program AVS3 encoding and compression platform supports multi-channel 8K UHD program encoding and compression, comprising multiple independent AVS3 encoding channels. After encoding and compression, output TS/IP program streams are delivered through the 8K UHD television IP integrated distribution platform to downstream users.

This encoding platform employs China' s independently developed, domestically researched new-generation AVS3 video encoding standard for 8K UHD applications, following the technical requirements of "Information Technology —Intelligent Media Coding Part 2: Video" (T/AI 109.2—2020). Audio employs 5.1 surround sound encoding. This innovative application will comprehensively drive the industrialization development of China' s independent AVS3 encoding standard.

3.4 CCTV-8K Network Entry and "Hundred Cities Thousand Screens" Promotion Application

CCTV-8K channel is delivered via China Cable Television backbone network to local cable television networks nationwide, and connected to Beijing Gehua and

Guangdong Cable TV networks to provide 8K UHD television channel services to users. Front-end encoding, network operator transmission, and user-end decoding all employ the AVS3 encoding/decoding standard, achieving China's first end-to-end full-link transmission using an independent video encoding standard.

To meet the people' s demand for watching the Winter Olympics in 8K UHD, CMG launched the "Hundred Cities Thousand Screens" UHD public service platform, delivering CCTV-8K UHD channel to over 30 cities nationwide including Beijing, Shanghai, Guangzhou, Shenzhen, and Tianjin, as well as to four stations on the Winter Olympics high-speed rail line (Qinghe, Yanqing, Taizicheng, and Chongli) with over 120 UHD large screens for Winter Olympics event broadcasting. The exquisitely clear and detailed competition picture quality delivered by 8K UHD technology provided the masses with the ultimate visual experience.

Addressing the challenge of watching large-screen television in public spaces without hearing accompanying audio, CMG developed the "Hundred Cities Thousand Screens Portable Audio" television audio transmission system. Viewers can download the "Hundred Cities Thousand Screens Portable Audio" mini-program to listen to CCTV-8K UHD channel audio on their mobile phones. The system uses mobile phone positioning information to identify the large screen, controlling audio-video latency to within 120ms. If audio-video desynchronization occurs due to mobile phone playback, fine-tuning is possible through the mini-program. The "Hundred Cities Thousand Screens Portable Audio" application scenario is shown in Figure 15 [Figure 15: see original paper].

As an innovation combining "technology + events," the "Hundred Cities Thousand Screens" promotion application represents the world' s first large-scale 8K technology application for opening ceremony live broadcasting and event transmission, bringing "Watch Winter Olympics in 8K" to the public and "zero-distance" demonstration of 8K Winter Olympics excitement to the masses, creating a new scenario for sharing the technological Winter Olympics.

Through 8K UHD application and practice at the 2022 Beijing Winter Olympics, China Media Group, relying on the State Key Laboratory of UHD Audio-Video Production and Presentation, achieved breakthroughs in technical research across the entire chain of UHD program production, signal exchange, encoding transmission, and user services. The group successfully promoted core equipment localization and built an internationally leading 8K UHD television production and broadcasting platform. By combining 8K UHD television channel network entry with "Hundred Cities Thousand Screens" UHD large-screen promotion and implementation, CMG innovated the 8K UHD television transmission service system, explored establishment of a new UHD television transmission model, and led the rapid development of global UHD television.

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Note: Figure translations are in progress. See original paper for figures.