EBU

OPERATING EUROVISION AND EURORADIO

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EBU MEMBERS' TRIALS OF 5G IN CONTENT PRODUCTION AND CONTRIBUTION

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1. Introduction

Audiovisual (AV) productions are the basis for broadcasting. Thereby a range of use cases is covered: news gathering, live productions such as music festivals with recording or sports events, but also documentaries etc. AV productions can be complex with a multitude of signals including video and audio signals, telemetry, communication, tally etc., which have to be transmitted together synchronously and error-free, often only with minimal latency. Especially for live productions, very high quality (Quality of Service, QoS) is extremely important, since live events cannot be repeated, and quality cannot be increased at a later stage.

Wireless productions can dramatically reduce the effort of a production. Setup time is shorter; changes are easier as there are no cables to install. This also means no safety measures to consider due to the risk of accidents caused by cables. As wireless equipment is mobile it allows the crew to react more spontaneously to developments at live events and get closer to people. Remote productions are also possible.

Wireless production equipment such as cameras, microphones, in-ear monitors, communications equipment, etc. have been in use for a long time. With conventional PMSE each of these devices needs its own radio link in its own frequency and dedicated infrastructure. This all means a high coordination effort, long planning and high costs, especially for larger productions.

In IP-based production, different signals are treated as individual IP streams. This principle is also needed in wireless productions. This is the motivation to study the latest generation of mobile communications technology, 5G, which offers high-performance connectivity in a global ecosystem with high data rates and low latency. It also offers new possibilities for media production and seems to be well suited for cloud- and IP-based productions.

5G specifications provide for various network configurations. The most common is a public mobile network deployed by a network operator (MNO) which provides "best effort" services without predictable or guaranteed QoS. Technically, QoS in public 5G networks could be increased with the help of traffic prioritization, network slicing or even by ringfencing part of the network for specific users[1], however, these options are not yet commercially available. So, if a guaranteed QoS is required, a dedicated, standalone non-public 5G network (sNPN) should be used. This option is particularly interesting for some media production use cases as the network can be configured to meet specific production requirements and is not shared with general public. 5G NPNs can be deployed permanently (e.g., in the production facilities or on campus) or temporarily (e.g., for the duration of an event).

The requirements for AV production using 5G NPNs were introduced in 3GPP in 2018 and gradually included in specifications, depending on the support from 3GPP membership. As the new functions become available, trials are carried out to evaluate the performance and identify opportunities and challenges.

[1] In 5G specifications this configuration is called Public Network Integrated Non-Public Network (PNI-NPN)

This report contains a collection of different trials conducted by EBU Members up to the time of writing. Each presents their respective technical configuration as well as their experiences with 5G NPNs in wireless AV production.

References and publications recommended for further reading are listed in the Annex.

2. BBC - News Coronation Trial

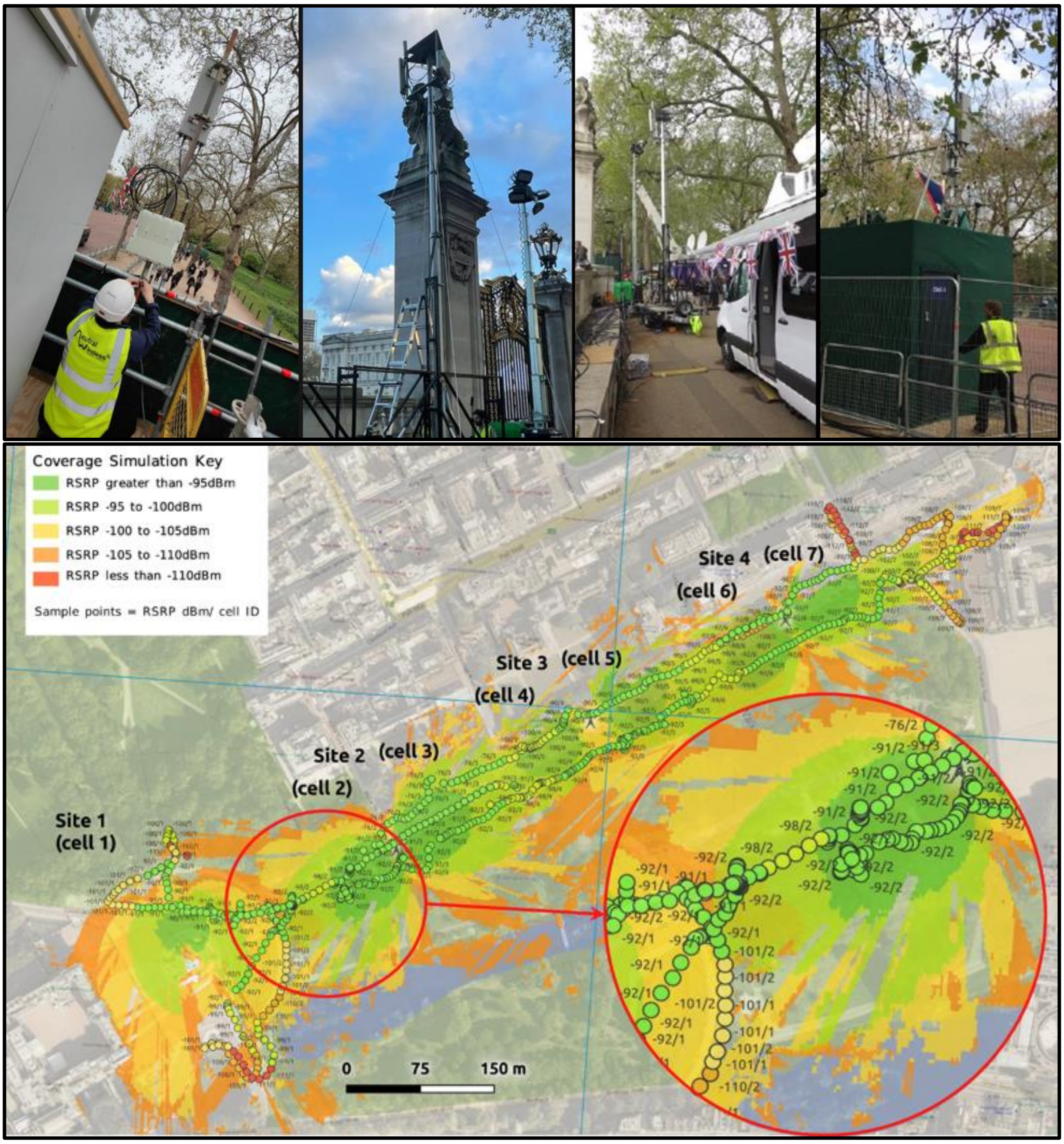
General Information	
Name of trial:	BBC News Coronation Trial
Name of the organisation:	BBC
Contact persons:	Mark Waddell (mark.waddell@bbc.co.uk), Simon Eley (simon.eley@bbc.co.uk)
Dates and places of the trials:	01/05/23 – 07/05/23 The Mall, London

2.1 Goals

The aim was to support multiple newsgathering organisations utilising their existing bonded SIM devices to provide live coverage from The Mall in the days leading up to and including the Coronation of King Charles III. Anticipating congested public mobile networks a 5G Non-Public Network (NPN) in the n77 frequency range was employed to provide reliable and guaranteed uplink capacity. A multi-cell network was deployed along the length of The Mall designed for continuous coverage and seamless handover. The performance of the network was closely monitored to capture data consumption for uplinks and downlinks, handover between cells and other metrics.

2.2 Setup

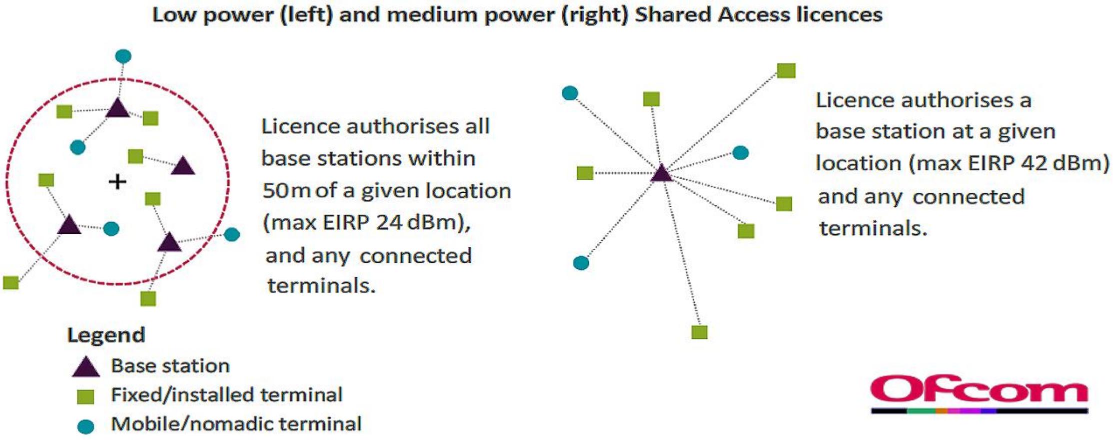
Neutral Wireless built a custom disaggregated network. The core network ran on a Xeon server, with four additional Intel i9 or AMD Ryzen 9 servers each running the VRAN for two radio cells. Remote radio heads were deployed at the designated cell sites along The Mall and connected back to their respective baseband units located in the media compound by dedicated single-mode fibre.



- Non-Public Network
- UL/DL ratio: 7:2.
- Agnostic support for bonded SIM devices from various manufacturers and connected cameras.
- Coverage along the length of The Mall from eight base stations at four locations with seamless handover.
- Coverage was predicted and confirmed with a walk survey, traffic and capacity were continuously monitored.

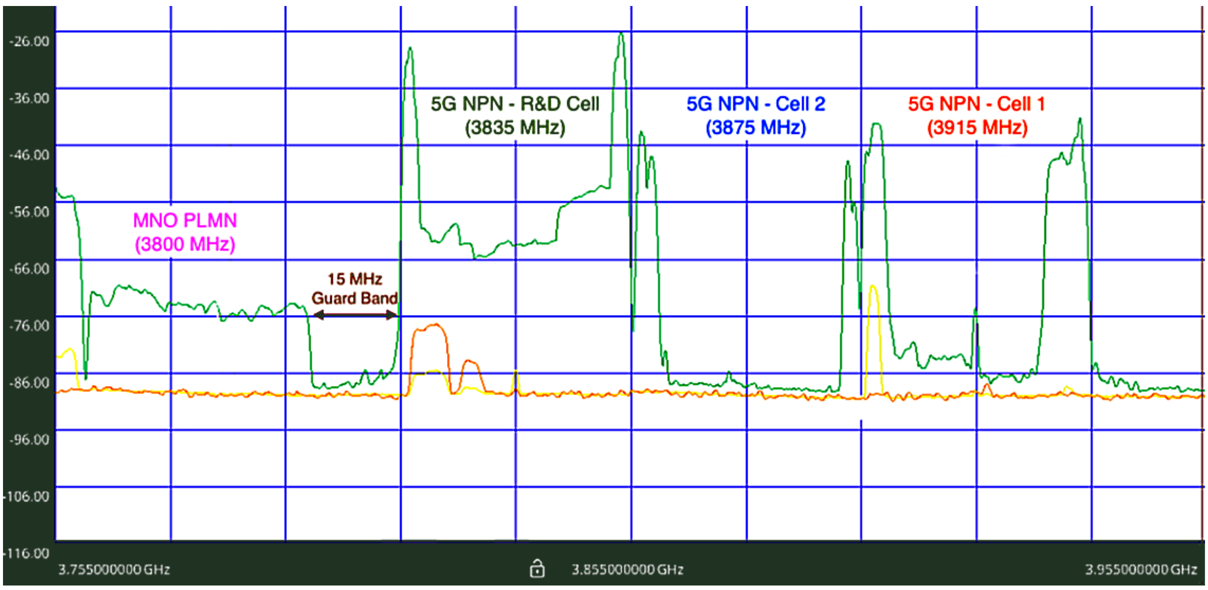
2.3 Spectrum

- One low power Shared Access Licence for initial test purposes and the separate low latency trial.
- Eight Medium power Shared Access Licences for the final network of base stations.



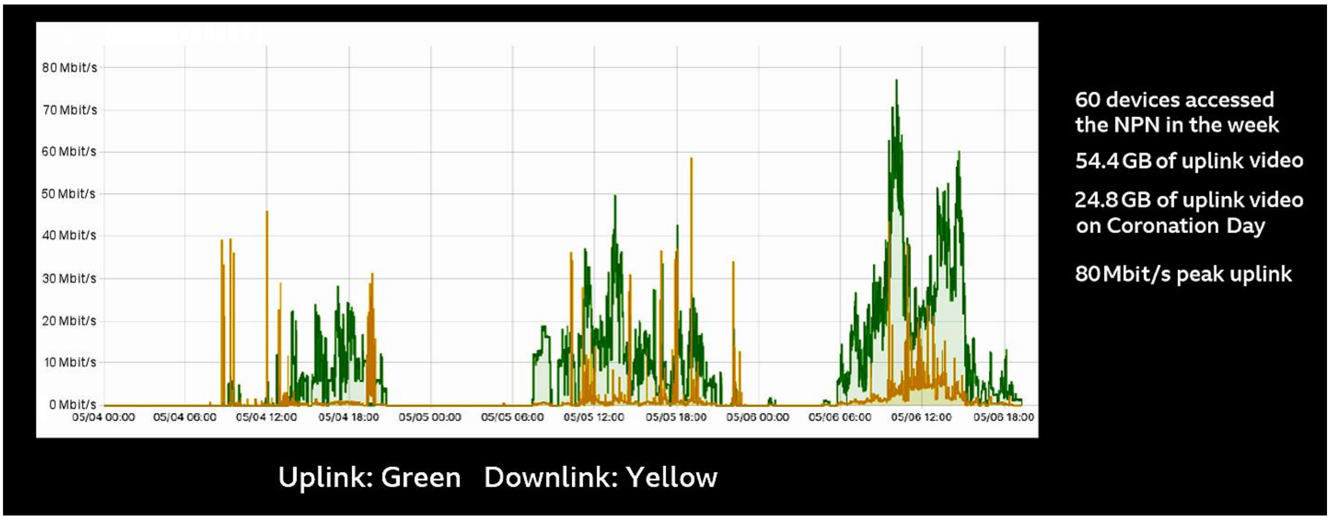
Network cell properties
Channels: A = 3815-3855 MHz [ARFCN 655666]; B = 3855-3895 MHz [ARFCN 658334]; and C = 3895-3935 MHz [ARFCN 661000]

Cell	Channel	Tx power (dBm)	Tx gain (dBi)	Rx gain (dBi)	Radio Head Tx/Rx Mode
1	C	26	14.0	14.0	1Tx 2Rx (diversity)
2	B	26	15.7	15.7	1Tx 2Rx (diversity)
3	A	16	14.0	14.0	1Tx 2Rx (diversity)
4	B	26	15.7	15.7	1Tx 2Rx (diversity)
5	A	26	14.0	14.0	1Tx 2Rx (diversity)
6	B	26	15.7	15.7	1Tx 2Rx (diversity)
7	A	26	14.0	14.0	1Tx 2Rx (diversity)
R&D	A	26	3.0	3.0 + 14.0	2Tx 4Rx (diversity)



40 MHz: 40*5*7/(2+7) = 156 Mbit/s capacity per base station.

2.4 Results



- Universal satisfaction from 30 users (2 SIM cards per user).
- The trial was designed to support multiple news gathering operations separate from but relieving pressure on spectrum for conventional COFDM cameras used by the main event coverage.
- Challenges included securing sufficient suitable spectrum in a timely manner given the extent of the network – Ofcom are investigating how to address this for the UK in the future.

2.5 Next steps

- More swift agile deployments by operators requiring less technical knowledge.
- Lobbying for more dynamic and straightforward access to suitable spectrum.
- Exploring similar IP Video links in non 5G NR spectrum e.g., 2 GHz and 7 GHz in the UK.

Further information

“5G standalone non-public networks: modernising wireless production”
https://www.ibc.org/download?ac=24630

3. BR – Camera in 5G Campus-Network

General Information

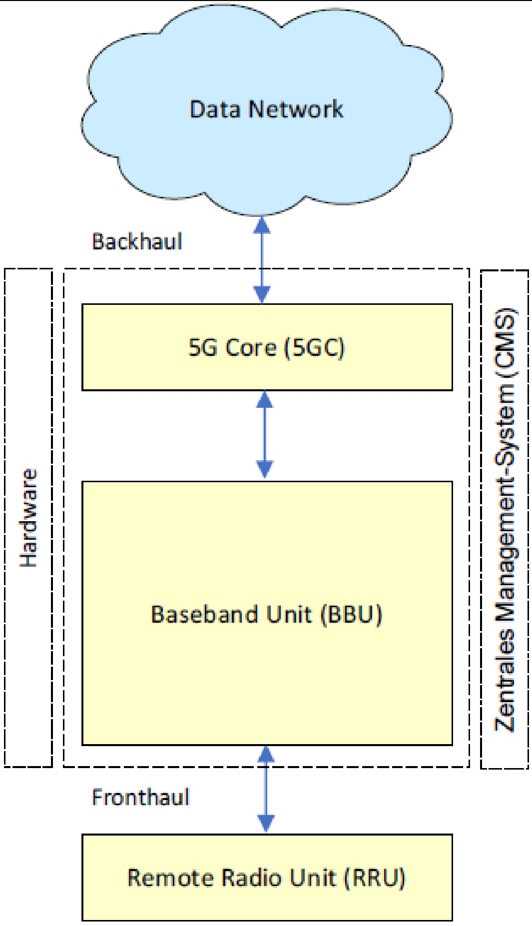
Name of trial:	Camera in a 5G Campus-Network
Name of the organisation:	Bayerischer Rundfunk
Contact person:	Roland Janik (roland.janik@br.de), Tobias Martin (tobias.martin@br.de), Christoph Over (christoph.over@br.de)
Dates and places of the trials:	11.10.2023, BR-Munich-Freimann

3.1 Goals

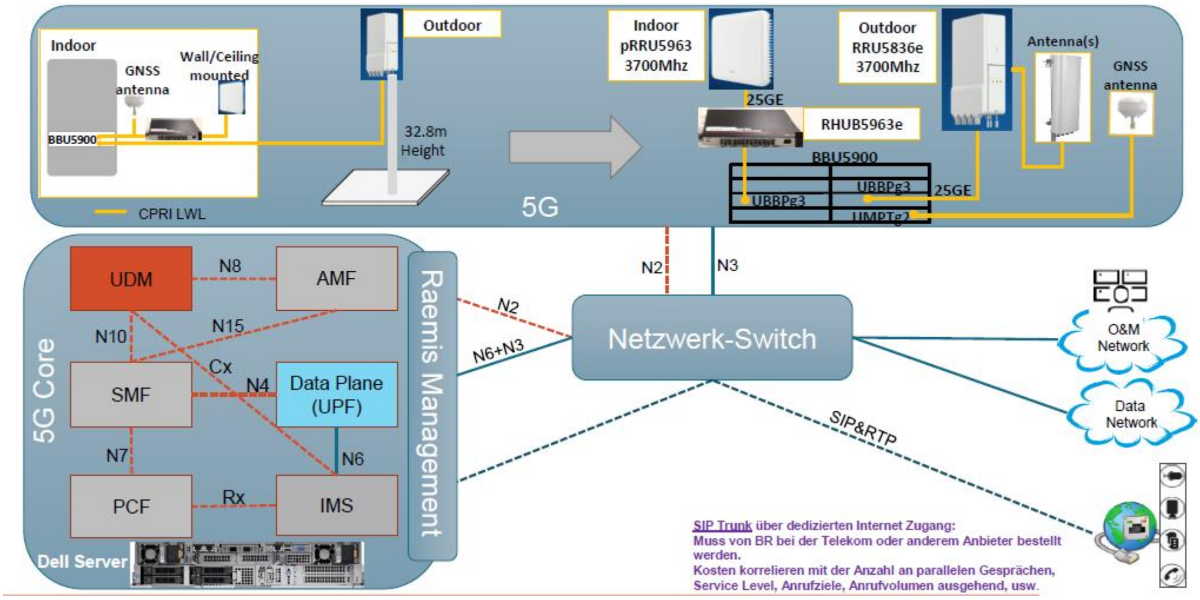
The signal of a camera could be transmitted with audio embedded in our 5G campus-network. It is possible to receive the signal of the camera via our BR-IT-network. Also, it is possible to transmit the tally signal to the camera and control the camera with the remote-control panel, which was also connected to the BR-IT-network.

3.2 Setup

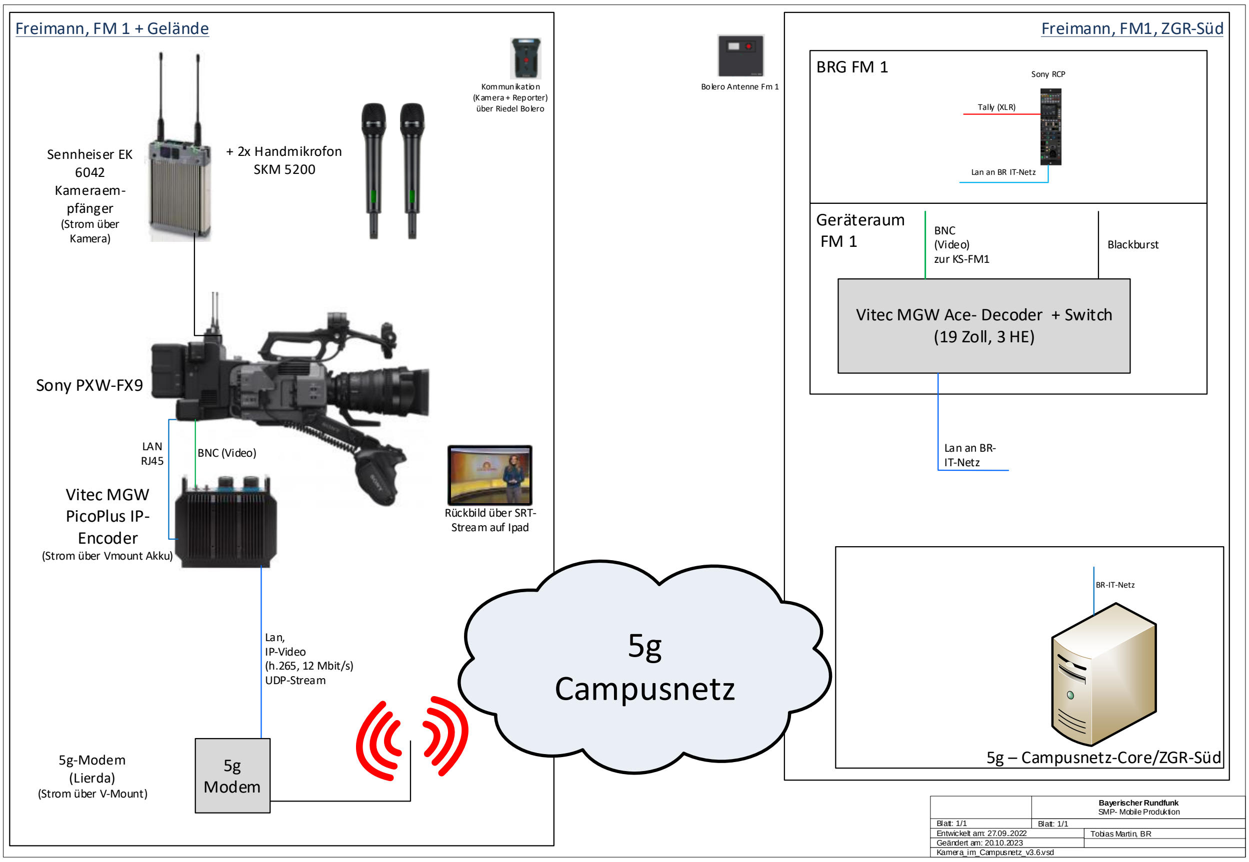
Principle System-Setup:



System Architecture:



Audio/Video Setup:



Different APN (Access Point Name) for Audio/Video and Voice in use because of different QoS Settings.

Type of 5G network:	non-public, with own IMSI
Network Configuration:	TDD Pattern 4:1 (DDDSU) according to EU harmonisation, synchronised to PN Provider. Due to this configuration UL/DL is measured with up to 350/1000 Mbit/s.
Type of equipment and vendors:	
Core:	Druid
Radios:	Huawei
BBU:	Huawei
RHub:	Huawei
Antennas:	Alpha Wireless
System Integrator:	Congiv, Munich
Smartphones:	Huawei, Apple, all supporting VoNR
Fixed location, nomadic, mobile:	Fixed location
Measurements:	Delay, latency, bandwidth, measured with iperf and R&S ROMES
Other wireless technologies used: in combination with 5G	Command via Riedel Bolero at 1.9 GHz DECT

3.3 Spectrum

3.7-3.8 GHz band

3.4 Results

- Latency about 200 ms,
- Bandwidth for the video about 12 Mbit/s.
- With optimized QoS settings: achievable UL/DL ratio of 350/1000 Mbit/s, RAN-latency around 10 ms.

No integration of the trial in the ‘main’ production is planned up to now.

3.5 Next steps

Tests with more than one camera

4. NRK – Robust Remote Production – Initial Trial

General Information	
Name of trial:	Robust remote production - initial 5G NPN trial
Name of the organisation:	NRK
Contact person:	Erik Vold (erik.vold@nrk.no)
Dates and places of the trials:	September-October 2021

4.1 Goals

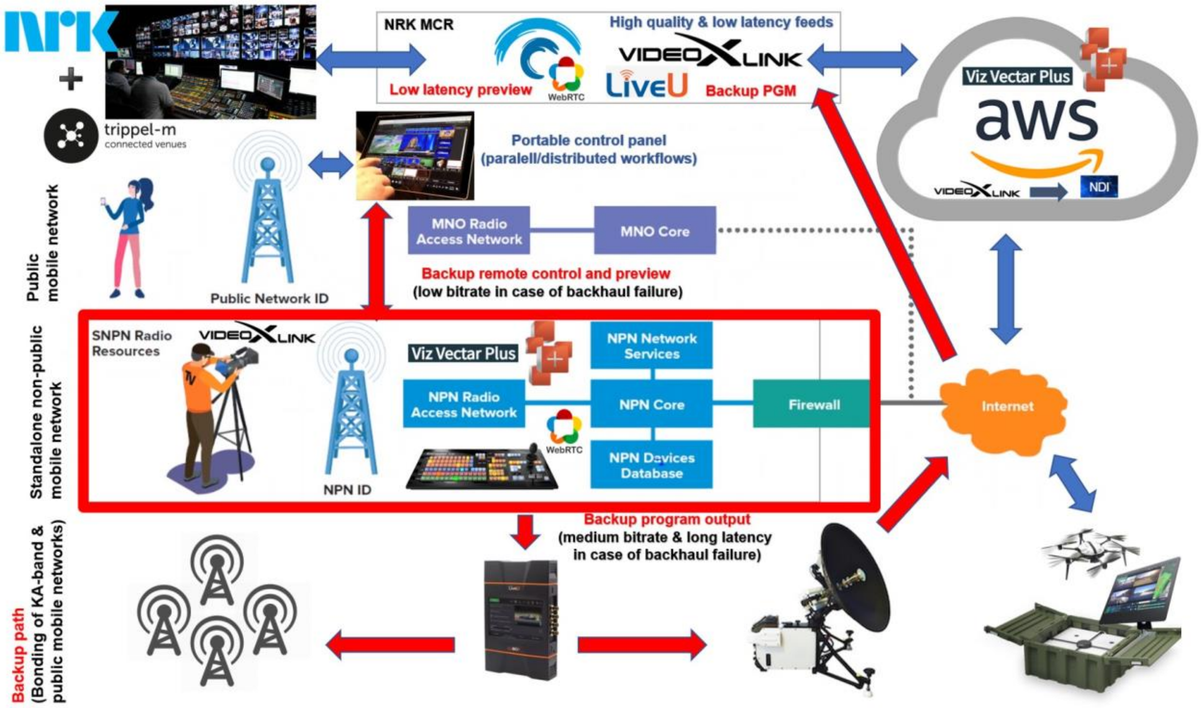
First trial with 5G standalone NPN aiming at implementing a robust wireless island with camera links on IP that would always be able to capture content. This is essential if we are a host broadcaster with other broadcasters using what we provide. The goal was to see if we could continue production in the 5G island when backhaul broke down. In this case the programme output should be made available through a backup link on satellite. We also tried to mirror the local vision mixer in the cloud to tailor for distributed remote production. By trying the most difficult parts all together we only expected to find pain points that needed further improvement in the years to come. This we did.

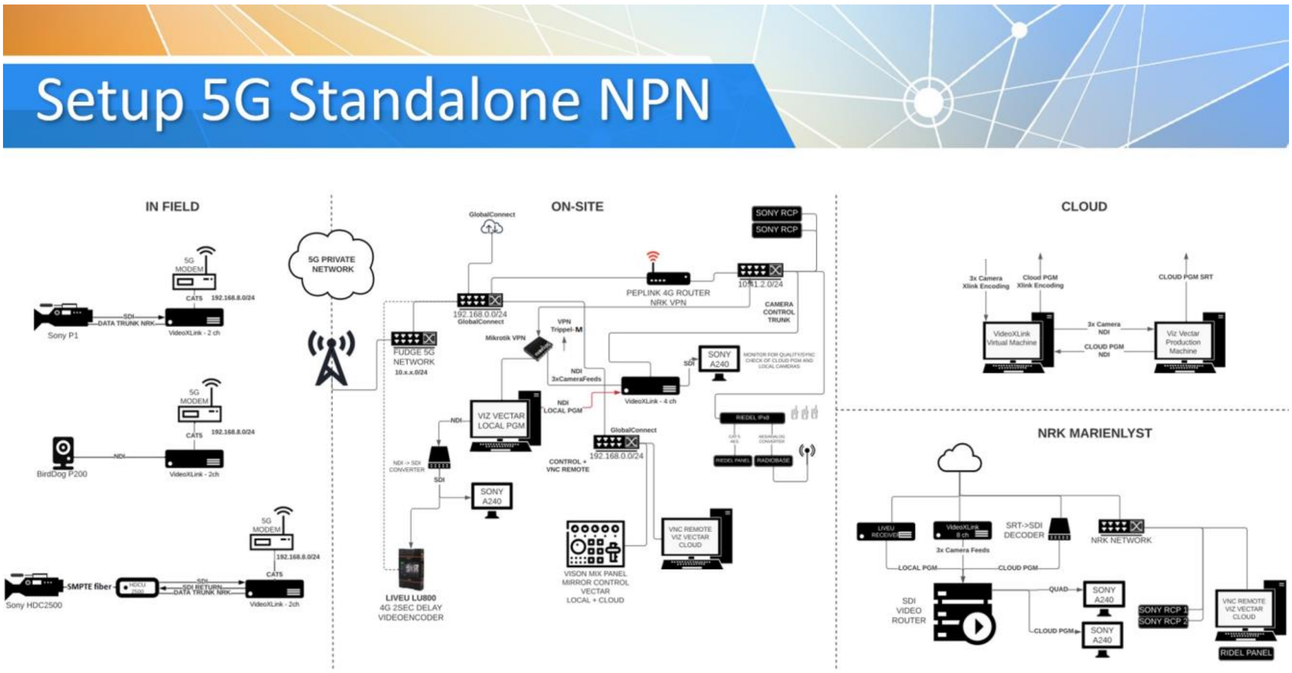
4.2 Setup

Fudge 5G partners:	Norwegian Defence (Cell on Wheels, Elverum) and Telenor R&D (5G equipment)
Type of 5G network:	Standalone Non-Public Network
Network configuration:	UL/DL ratio 1/4
Type of equipment:	Athonet core, Huawei 64 x 64 mMimo, Huawei CPE Pro 2, Sony camera/ RCP, VideoXlink encoders, NDI integration, professional local vision mixer and audio mixer and an additional vison mixer in the cloud (Viz Vectar Plus) etc., Satellite used as backup feed (with LiveU)

Nomadic setup but fixed location

Conceptual setup:





4.3 Spectrum

WiMax frequencies (3552-3592 MHz, 40 MHz bandwidth) – Made available by Telenor R&D

4.4 Results

As the production against the cloud was the mirror of a local variant, we should have been capable of producing locally on our 5G links when the backhaul failed. But due to some dependencies on services deep within the fixed network at the provider (as well as the fact that the Huawei CPE pro 2 could not bypass the problem by activating bridge mode) we could not demonstrate robust local production by simply pulling the plug to the internet. Outgoing media streams also depended on an early version of RUDP against the Viz Vectar Plus mixer in the cloud (the NDI bridge in NDI5 was still beta, where WAN was not enabled), it was therefore difficult to demonstrate mirrored remote production. We nevertheless gained useful intelligence with 5G Core where we realized that Athonet run on available hardware had too few resources and a highly varying RTT was too demanding for VideoXlink (a large proportion of FEC and resend gave a low useful data rate and long latency).

There was some improvement throughout September and on a second occasion during the next innovation days we could test on a more stable network, regaining the belief that 5G NPN could be used for high end production. During this trial we also learned that there were some common needs both among Norwegian defence/emergency services and event productions such as Trippel M, that we have to solve together. Also, the operators'/vendors' R&D resources started teaching us the language we needed for specifying our needs when tailoring relevant services and building a new value chain for private 5G. The most important thing in this trial was that the collaboration with Fudge 5G was established and that we got good measurement tools for further development (VideoXlink proved to be very suitable for both reading continuous data regarding packet loss, reconstruction, RTT etc., far more detailed than with NDI, and their data trunk proved to the salvation for the cloud integration in the next trial).

5. NRK – Robust Remote Production with Cloud based Parallel Workflows – 2nd Trial

General Information

- Name of trial:	Robust remote production with cloud-based parallel workflows – Second 5G NPN trial
- Name of the organisation:	NRK
- Contact person:	Erik Vold (erik.vold@nrk.no)
- Dates and places of the trials:	30-31. October 2021 in Holmenkollen

5.1 Goals

In the second trial of 5G SNPN, we aimed to go on air with "Hopp NM" using 5G as part of a fully-fledged IP-based remote production (live on NRK1). The setup was mirrored as parallel remote productions, one through the cloud with a control room used by Trippel M Connected Venues and one with direct feeds through MCR with control room used by NRK. This demonstrated effective workflows.

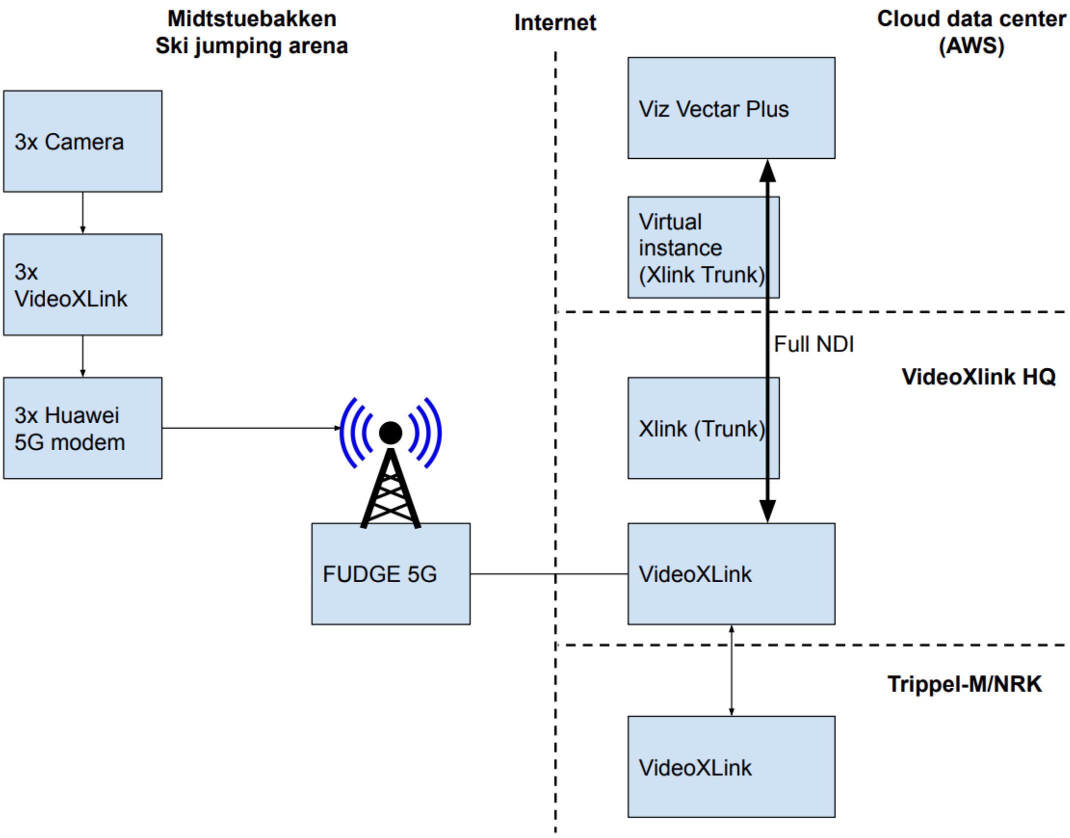
5.2 Setup

Fudge 5G partners:	Norwegian Defence (Cell on Wheels, Elverum) and Telenor R&D/Huawei (5G equipment), full production crew at NRK (remote production), Trippel M connected venues (cloud-mirrored setup), Cumucore (5G Core), VideoXlink (encoders and decoders)
Type of 5G network:	Standalone Non-Public Network. Backhaul connected with fibre to NRK (IP).
Network configuration:	UL/DL ratio 1/4
Type of equipment:	Cumucore 5G core, Huawei 64 x 64 mMIMO, Huawei CPE Pro 2, Sony camera/ RCP, VideoXlink encoders/decoders, full NDI integration through VideoXlink HQ connected to AWS, professional central vision mixer and audio mixer (at NRK) and an additional vison/audio mixer in the cloud

	(Viz Vectar Plus) etc. Simultaneous access to the same content on multiple control rooms/crews.
Nomadic setup:	Cell on Wheels (COW1) placed at the base of the hill giving coverage to 3 cameras.

Conceptual setup:

Actual setup:



5.3 Spectrum

WiMax frequencies (3552-3592 MHz, 40 MHz bandwidth) – Made available by Telenor R&D

5.4 Results

Only three of the cameras were on 5G NPN. These were doubled as a wireless part of a total of 11 wired cameras. There was thus no risk in the implementation. This was fortunate because even though the 5G core had now been switched to the more resourceful hardware running Cumucore, it turned out that it was only stable for 6-7 minutes, after which packets were lost for about one second (a buffer error; the issue was solved after production). At that second, we had to cut to wired cameras to camouflage the short-term outcome.

There were also glitches in the audio, however these were only in the non-critical cloud integration with monitoring return feeds (no time to solve properly). Aside from this periodic error, everything worked very well in this trial, and we were able to stretch our ambitions a little further.

Triple M manage to implement an image mixer in an AWS cloud and integrate it with our 5G island in Midststuen (adding only 60 ms delay). VideoXlink provided a contribution (using Xlink protocol with UDP retransmission) to their headquarter in Stockholm and the last bit to AWS was done with full NDI in the data trunk towards the Viz Vectar Plus cloud software (on 10 Gbit/s fibre; no need for UDP retransmission or heavy compression on the AWS-link).

The parallel workflow with two control rooms having access to the same content was demonstrated, and for the first time, wireless IP was on air (in parts of the production). With a quality limited by fairly low bitrate (15-20 Mbit/s UDP, depending on position) we have to look for better uplink ratios (changing frame structures and MIMO configurations) and more bandwidth. We also identified a need to experiment more on all wireless setups as this will enable a more economic setup (reduced time on rig previous to the event) and a more lightweight, user-friendly and portable setup for general use in all types of production.

6. NRK – Wireless and Flexible Remote Production – 3rd Trial

General Information

Name of trial:	Wireless and flexible remote production – Third 5G NPN trial
Name of the organisation:	NRK
Contact person:	Erik Vold (erik.vold@nrk.no)
Dates and places of the trials:	November 2021 in Sjusjøen (near Lillehammer)

6.1 Goals

In the third trial of 5G S-NPN the primary goal was to test an all-wireless setup to see if we were able to cover a more demanding biathlon with fewer cameras in an IP-based remote production (from a control room in Oslo belonging to Trippel M connected venues). Normally this would require 20 cameras. In the trial we tried covering the event with only 6 cameras to see how much help we got from remote controlled PTZ (pan tilt zoom) and wireless cams changing positions during production.

We also aimed at testing increased uplink speeds when doubling the available bandwidth and changing the frame structure from 1 up and 4 down (20% uplink) to 3 up and 7 down (30% uplink).

6.2 Setup

Fudge 5G partners:	Norwegian Defence (Cell on Wheels) and Telenor R&D/Huawei (5G equipment), production crew from NRK and Trippel M connected venues (remote production), remote production equipment from Trippel M (cloud setup and cameras on site), Cumocore (5G Core), VideoXlink (encoders and decoders)
Type of 5G network:	Standalone Non-Public Network. Backhaul connected to Trippel M (IP).
Network configuration:	UL/DL ratio 3/7
Type of equipment:	Athonet 5G core, Huawei 64 x 64 mMIMO on WiMax frequencies (3552 MHz, 40 MHz BW), alternative antenna from the Norwegian defence on NATO frequencies (3300 MHz, 80 MHz BW), Huawei CPE Pro 3, Sony camera/ RCP, VideoXlink encoders/decoders, full NDI integration through VideoXlink HQ connected to AWS, professional central vision mixer and audio mixer (at NRK) and an additional vison/audio mixer in the cloud (Viz Vectar Plus) etc.
Nomadic setup:	Cell on Wheels (COW1) placed near the cafeteria on top of the hill covering most of the production area with line of sight.

Physical setup of camera and Cell on Wheels

(moved according to red arrow, see trial 1/2 for details):

6.3 Spectrum

1. WiMax frequencies (3552-3592 MHz, 40 MHz bandwidth) – Made available by Telenor R&D.
2. NATO frequencies (3300-3080 MHz, 80 MHz bandwidth) – Made available by Norwegian defence.

6.4 Results

The part that we did not plan to test gave us the most valuable learning experience. As this trial took place in the Covid-19 Pandemic we had to reduce accreditations by 50% at short notice. Therefore, the 5G team with the Cell on Wheels had to move outside of the production area prior to production. If all cameras had been cabled to an OB-van this move would normally be impossible at such short notice (with fibres installed beneath the crowd and slopes). But since every camera link was wireless the move had very little consequence and we were able to continue production.

We also experienced more valuable flexibility with standalone NPN: The autonomous feature of our nomadic network. In the morning of production, the fibre connecting the network to the backhaul was run over and broken by a vehicle. This was quickly solved merely by reconnecting the 5G core to the normal internet in the cafeteria near to the Cell on Wheels. With local core we were not dependent on special connections to the operator’s core and could use any available normal internet connection.

For this test, we went back to using the more stable 5G core from Athonet (Telenor set this up with support from researchers in the Fudge 5G collaboration). From the first test, the Norwegian Defence Research Institute (FFI) provided a Huawei 64 x 64 massive MIMO antenna that used the WiMax frequencies (40 MHz), but in this trial we also tested a new antenna with double the capacity, where we had 80 MHz in the NATO band (3300-3380 MHz).

The downlink to uplink ratio was 7:3 (30% uplink). This improved the bitrate for uplink by 50% compared to 4:1 in previous trials (20% uplink previously, the same as public networks). We measured upload speeds of a maximum of 105 Mbit/s for 40 MHz and 210 Mbit/s for 80 MHz on TCP. In practice, we were only able to use a third of this on stable UDP using Xlink when we wanted minimal error rates (allowed to use 20% of the bitrate on FEC and add 40 ms on resend). The cause of this major difference could be UDP retransmissions in Xlink protocol resulting in bitrate-peaks (need for headroom) and non-optimized MTU sizes.

40-50 Mbit/s turned out to be sufficient for good visual quality in remote production (VideoXlink used H.264 coding). This was possible with 80 MHz bandwidth but only on two cameras in the same sector. With 6 cameras the bitrate dropped to 15-20 Mbit/s, and we could see artifacts on fast moving images.

We achieved 120 ms on the lowest latency setting, but in practical and robust settings with sufficient buffers we ended up with 7 frames latency (280 ms with 1080i at 25 fps). Other encoders can go lower.

We believe it is possible to reach higher bitrates with smaller MTU sizes as well as a larger upload share in alternative frame structures (Neutral Wireless demonstrated 2 down and 7 up: 77% uplink) and MIMO configurations favouring uplink (CPE Pro 5 has three uplink antennas, where two of them can be used for 5G, resulting in almost double uplink capacity compared to CPE Pro 3).

It is also desirable to have more weather-robust modems than the Huawei CPE Pro 3. The prototypes worked well in this trial, but we lost one of the cameras after a long day at -18 degrees. With only 6 cameras and the loss of the most critical handheld camera, this influenced the quality of production.

This was nevertheless a very valuable learning experience where we could see the significant benefits of both a local core (nomadic features: connecting to any type of internet for backhaul) and dedicated frequencies (gaining the ability to change into uplink-favouring frame structures and guaranteed capacity not shared by the crowd).

This all-wireless setup has potential to act as a portable solution for emergency response and news coverage in combination, as well as being a cost-efficient production unit increasing the type of events we/Trippel M are able to cover cost efficiently and with fewer CO_2 emissions (remote production reduces the transport of both production team & equipment).

7. NRK – Wireless Part of High-End OB-Production – 4th Trial

General Information

Name of trial:	Wireless part of high-end OB-production. Fourth 5G NPN trial
Name of the organisation:	NRK
Contact person:	Erik Vold (erik.vold@nrk.no)
Dates and places of the trials:	June 2022 in Skien ("NM Veka")

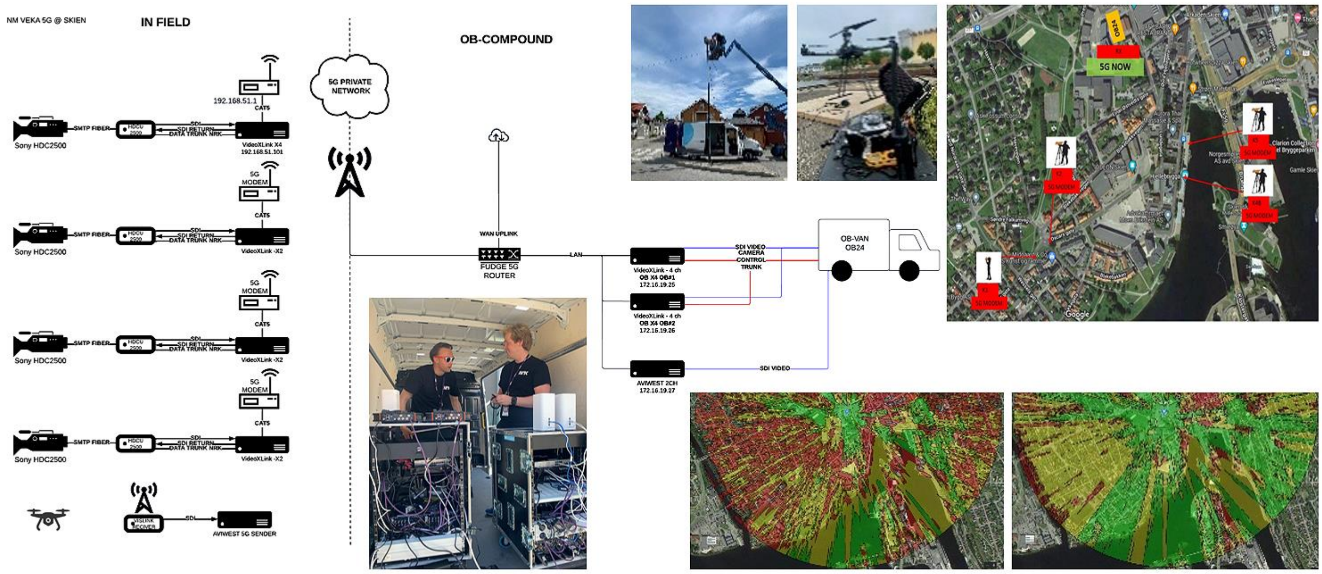

7.1 Goals

In the fourth trial of 5G S-NPN the primary goal was to test fully integrated wireless cameras in high-end OB-production (camera control, return, tally, IFB etc). "NM Veka" was aired on NRK1. The aim of the trial was to make the experience as similar as possible for the operators (photographer, camera control and director) and to test 5G as an alternative to fibre. We also planned to test coverage in a far more challenging and hilly urban area. At larger distances (from 1 to 3 km) we retested increased uplink speeds achieved in the previous trial by doubling the available bandwidth (from 40 MHz to 80 MHz) and changing the uplink ratio from 1 up and 4 down (20% uplink) to 3 up and 7 down (30% uplink).

7.2 Setup

Fudge 5G partners:	Norwegian Defence (Cell on Wheels) and Telenor R&D/Huawei (5G equipment), production crew from NRK and remote production equipment from Trippel M (Remote production part is not described in this trial but they built a full cloud setup to duplicate the functions in NRK's OB and in a neighbouring classroom they established a control room to simulate parallel workflows), Athonet (5G Core), VideoXlink (encoders/decoders), AviWest/Haivision (encoders/decoders).
Type of 5G network:	Standalone Non-Public Network
Network configuration:	UL/DL ratio 3/7
Type of equipment:	Athonet 5G core, Huawei 64 x 64 mMIMO on WiMax frequencies (3552 MHz, 40 MHz BW), alternative antenna from the Norwegian Defence on NATO frequencies (3300 MHz, 80 MHz BW), Huawei CPE Pro 3, TD-Tech outdoor CPE w/PoE, Sony camera/RCP, VideoXlink, AviWest/Haivision Pro 460 encoders (+decoders) one drone, etc.
Nomadic setup:	Cell on Wheels (COW1) placed near the OB-truck on top of the hill covering most of the production area.

Physical setup of camera (5G part only):



7.3 Spectrum

1. WiMax frequencies (3552-3592 MHz, 40 MHz bandwidth) –Telenor R&D.

2. NATO frequencies (3300-3080 MHz, 80 MHz bandwidth) – Norwegian Defence.

7.4 Results

The coverage was improved by lifting CPEs 5-7 metres in light poles/cranes (see illustration above).

We achieved 70 Mbit/s stable UDP uplink on 80 MHz and 40 Mbit/s stable UDP uplink with 40 MHz BW.

For all cameras except the drone (0.8 s) we used 280 ms delay. HERE is a more detailed report.

The trial in Skien was the first where we introduced users to 5G technology in a full production flow. The user experience was therefore in focus, and it was important for us to get feedback from them concerning:

How to standardize the technology into the external workflows and integrate with the production units of NRK (OB24)	It is relatively cumbersome to transfer all functions to an IP-based workflow in the field. The racks are quite time-consuming to build for each production, and it will be cost-effective to standardize these for both remote production and 5G workflows. If the camera manufacturers do not come up with a "CCU-less" workflow, we are completely dependent on building setups outside the cameras.
Listen to the users and hear what their biggest concern in production is	We believe that latency is the most noticeable consequence of doing productions over 5G. But it seems that the level of delay is acceptable for workflow in most productions.
Testing 5G SNPN in urban environments without direct line-of-sight to the antenna	This requires preparation and testing. Mapping of coverage and well-thought-out antenna and camera positions are absolutely necessary.
Expand your experience with different encoders and modem solutions	We got a good impression of Aviwest, and it seems like a simple "plug and play" solution that clearly shows that it is possible to make things more rugged. The test shows that there can be great advantages in splitting up the CPE and encoder, but this can perhaps be solved in the future with an external antenna.
Get hands-on experience on how camera chains work in remote production	The camera chains mostly work well. We miss interfaces other than analogue connections, but it is possible to create robust solutions around this. We see several similarities between the challenges in 5G and remote production.
Get more hands-on experience with compressed video and IP-based production	As mentioned above, delay is the most notable difference. We have received little concrete feedback about significant quality differences in video with the different solutions.

8. NRK – Wireless Production on Telia's frequencies and N40 (2.3 GHz) – 5th Trial

General Information

Name of trial:	Wireless production on Telia's frequencies and N40 (2.3 GHz) Fifth 5G "NPN" trial
Name of the organisation:	NRK
Contact person:	Erik Vold (erik.vold@nrk.no)
Dates and places of the trials:	October 2022 in Bergen

8.1 Goals

In the fifth trial of 5G "NPN" the primary goal was to investigate the performance of the 2.3 GHz band to see whether it fits multi-camera production, and how well an upgraded public network would work for media content production.

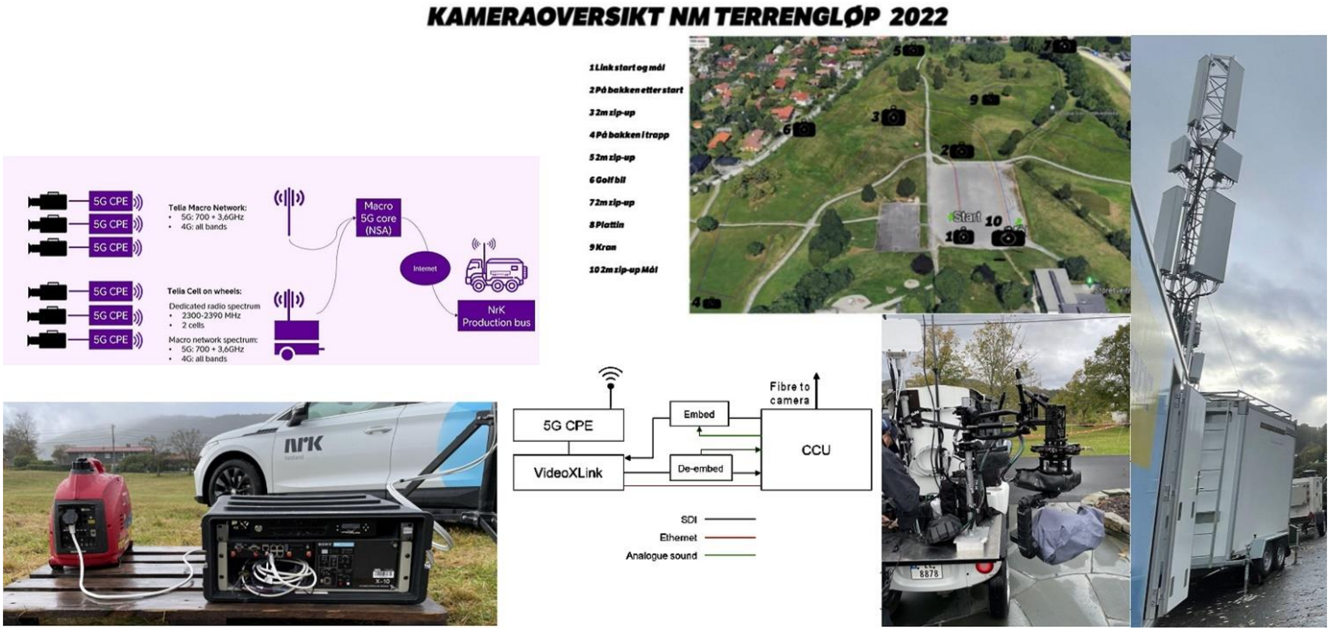
This was also a first look at what Telia could offer in Private 5G as a service.

Production of "Terreng NM" tried to follow athletes in terrain: Ideal for testing coverage and latency.

8.2 Setup

Partners:	Telia (5G Core in Oslo and radio from Ericsson) and from Fudge 5G: Norwegian Defence (CPEs), production crew from NRK and Trippel M connected venues, VideoXlink (encoders/decoders)
Type of network:	Non-Standalone 5G Network (Telia core) enhanced with private frequencies (N40)
Network configuration:	UL/DL ratio 1/4
Type of equipment:	Two Ericsson MIMO antennas on N40 (2300 MHz, 80 MHz BW), two alternative antennas from the Telia on public 4G frequencies (1800, 2100, 2600 MHz) and two alternative antennas from the Telia on public 5G frequencies (3600 MHz), 3 Xiaomi phones used as modems, Celerway CPEs, Sony camera/RCP, Grass Valley Camera LDX 150 with internal CCU (IP controlled), VideoXlink encoders/decoders, Lynx embedders/de-embedders for integration to intercom and IFB.
Nomadic setup:	Cell on Wheels placed in the centre (camera in upper part is behind hills & trees).

Conceptual setup:



8.3 Spectrum

1. 5G – N40 frequencies (2310-2390 MHz, 80 MHz bandwidth) – NKOM
2. 5G – N77 frequencies (3600 MHz, 80 MHz bandwidth) – Telia.
3. 4G frequencies (1800, 2100, 2600 MHz, 20 MHz BW) – Telia.

8.4 Results

Logistics in the field and associated rigging time is still a challenge. We need simpler integration.

Power consumption with more equipment in the field is also a problem and power generators are not an ideal solution due to noise, etc. Our solutions need to be able to compete with the simplicity and quality of video over fibre. The presented setup can evolve to an acceptable level. Easier modular and lightweight mobile solutions are desired. We're able to reduce external rack with internal CCU on GV.

Several conclusions can also be extracted from network behaviour and latency:

In the tests performed, a latency of approximately 350 ms on video was achieved. This value was not noted as a problem by the camera operator, but it is desirable to find encoders that can get below 100 ms to be able to cover all kinds of content (Camera control needs to be responsive when following athletes).

It should be noted that some limitations were found when using public networks. During the week in Bergen, several tests demonstrated that the use of public 5G networks as a replacement for wireless links in high-end production is not an option. It might work well for newsgathering, similar to the 4G remote contribution scenarios today with LiveU or similar systems (aggregating MNOs, long delay). It is insufficient, however, in a multi-camera context with low delay, high capacity, stringent handover requirements, and need for stable mission critical control functionalities.

Some of the points encountered as problematic with public networks are the following:

Data capacity: Little or no control over how many devices use the network simultaneously. High capacity is demanded to support multiple cameras simultaneously. We also need stable capacity & stable RTT for seamless transitions between all of them with no timing glitches or visible artifacts.

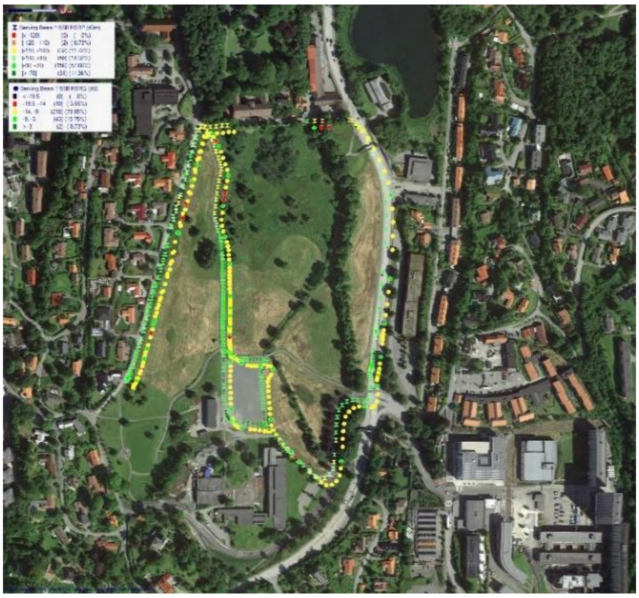
Handover: Limited ability to control handover since it is controlled by the base stations. During handovers between base stations, the performance drops below an acceptable level (in non-standalone 5G networks it seems 5G is dropped, 4G then takes over, before reconnecting the 5G part). In standalone 5G networks, it is expected that the handover will be faster and will affect performance to a much lesser extent as the connection will stay on 5G (Should implement local core).

At public 3.6 GHz, it is not possible to set a frame structure that provides a high uplink ratio (only 20% uplink).

This is a major reason we need dedicated frequencies (uplink ratio not limited to public setting).

RTT/latency: by sending the data to the centralized core, RTT and latency times vary greatly over time. Varying RTT is an issue for the encoders capacity on the link as it triggers a resend of the packets over UDP, resulting in bitrate-bursts (need for higher headroom when capacity is not optimized). A local core provides us with the ability to maintain control on capacity and handover.

Coverage: if there is poor coverage on 5G, UEs[2] can fall back to 4G, which is not desirable. We also measured a major difference between coverage in lower frequencies (i.e., 2.3 GHz) on the left side and higher frequencies (3.6 GHz) on the right side here. N40 is able to give link on cams behind hills/trees:



A **full report is available HERE.**

[2] UEs: User Equipment units / user devices.

9. RAI – 5G Jam Session – An Experiment of Combined Arts

General Information

Name of trial(s):	5G Jazz Jam Session – An Experiment of combined arts
Name of the organisation:	Rai Radiotelevisione Italiana
Contact person:	Luca Vignaroli (mluca.vignaroli@rai.it), Giulio Stante (mgiulio.stante@rai.it)
Dates and places of the trials:	2022, OGR[3], Corso Castelfidardo, 22, 10128 Torino, Italy

9.1 Goals

The "5G Jazz Jam Session" use case aimed at the creation of a new kind of live event where the artistic performance is executed simultaneously in several remote locations but, nevertheless, it is perceived as a unique seamless show by the spectators gathered in the main venue.

In particular, this specific artistic experiment involved the musical performance of a Jazz Big Band (the Big Band GP Petrini), whose musicians were displaced in three different spatially separated areas of the venue. The musicians were asked to play together by means of a dedicated 5G Private Network. Moreover, remote TV production was also realized through a remote control-room hosted in a separate building connected via a 1 Gbit/s microwave link.

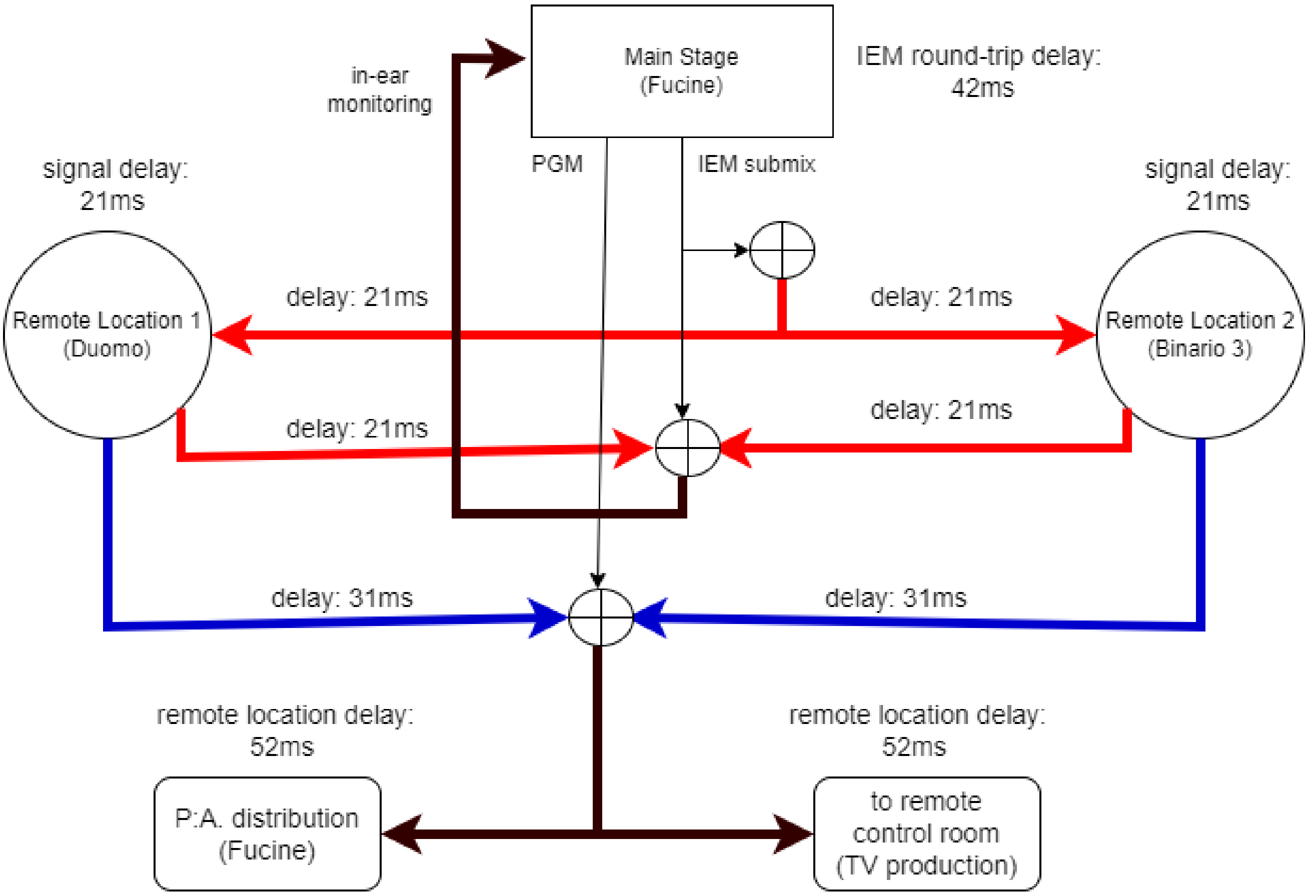
Latency and jitter of audio monitoring signals are the main key performance indicators for this use case. It is basically the in-ear monitoring sound mix (from the main stage to the remote locations) used by remote musicians to listen to the remote performance and to keep in sync with the rest of the band. In addition, another important KPI is the perceived latency of the remote instruments by the spectators gathered in the main hall.

9.2 Setup

Type of 5G network:	5G SA NPN (Release 15)
Network Configuration:	duplexing scheme TDD, radio scheme 6:4
Type of equipment and vendors:	The 5G network is based on the Nokia NDAC solution.5G modem: Nokia 5G router FRRx502e. RAN: AWHQE 5G AirScale Micro RRH 4T4R n78 + Airscale BBU ASOE.
Audio equipment:	DirectOut with Rav.IO card + Vivivaldi soluton for tunnelling-based audio transport over 5G network.
Video equipment:	Haivison Pro460 + SDI cameras + Vitec MGW ACE encoder/decoder + J2K Lawo encoder/decoder.
The 5G network:	The 5G network is based on fixed location, indoor setup.

[3] Turin's *Officine Grandi Riparazioni*, a site built between 1885 and 1895, was once dedicated to the maintenance of railway vehicles and is now committed to the promotion of culture and technological innovation in the fields of the visual and performing arts.

Overview diagram/description of the setup:



Inside the OGR, three different areas/halls were reserved for the use case. In the main hall we placed the majority of the band, while the remote locations hosted a couple of soloists each. All musicians were asked to play together. Audio and video signals travelling between these three remote locations were carried through the 5G network. The above diagram represents the audio signal setup. Audio monitoring signals (red arrows - sound mix of the main stage) were provided to remote musicians.

These signals are low-latency low-quality. In addition, audio contribution signals instead (blue arrows - musical performance or remote musicians) were sent back to the main stage for p.a. These signals have higher latency and higher quality. Moreover, other types of signals (video signals, o&m signals, etc.) also travelled through the network, but they are not represented in the diagram.

9.3 Spectrum

BW: 60 MHz (belonging to the ISP Opnet); 2440-3500 MHz, N78 band.

9.4 Results

Network latency, network coverage and network performance were validated by Nokia engineers.

Here are some results:

- Uplink capacity per cell: >140 Mbit/s
- Uplink RTT: 12 ms (average); 26 ms (90th percentile); 32 ms (99th percentile)
- Latency of audio monitoring signal: 21 ms
- Latency of audio contribution signal: 31 ms
- Latency of video monitoring signal: 73 ms

- Latency of video contribution signal: 300 ms
- Total perceived latency of remote instruments by spectators in the main hall: 52 ms

An integration of the trial in ‘mainstream’ production is still under discussion. However, this specific use case is probably not yet ready for “mainstream” production, as discussed below.

Key observations:

- For audio monitoring signals, the achieved delay of 21 ms has to be considered just enough to enable the specific use case and to allow musicians to play in a satisfactory way.
- Songs with faster tempo required even lower latency figures to allow the band to play together.
- One-way delays greater than 30 ms must be considered excessive and usually resulted in musicians being unable to play together.
- The perceived delay of remote instruments with respect to the rest of the band was about 52 ms. According to the audience present in the main hall and to TV spectators, the user experience was good. Some participating spectators were later interviewed and all of them confirmed the perception of the performance as a unique show. However, on the contrary, expert listeners reported to perceive such a slight delay between the sound-mix (coming from the main stage) and the remote instruments (coming from the remote locations)

Challenges	***Countermeasures***
Minimum Latency & Jitter	Radio scheme changes to 6:4, QoS configuration through different APns, Frame size reduced, ST2022-7 implementation
PTP & Intercom over 5G	Not solved. Provided by fixed network (optical fibre)
Multicast in UL	Solved for audio using Vivivaldi Solution
Network traffic segregation	L3 VPN over IP/MPLS architecture (VPRN)
Network visibility among remote devices belonging to the same category	L2 VPN over IP/MPLS architecture (VPLS)

9.5 Next steps

Not planned yet.

9.6 Further information

5G Jazz Jam Session - An experiment of combined arts: IBC 2023, Amsterdam — G. Stante, D. Airola Gnota, F. Debandi, M. Serafini, L. Vignaroli, F. Graglia, G. Scozza, E. Mastromartino, M. Fiammengo, L. Guida

10. SWR – 5G Campusnetz

General Information

Name of trial(s):	5G Campusnetz
Name of the organisation	SWR
Contact person	Roland Beutler (roland.beutler@swr.de), Ralf Baron (ralf.baron@swr.de)
Dates and places of the trials	2021 - present time, Baden-Baden, nomadic production sites

10.1 Goals

The goal of the 5G Campusnetz project is to explore the potential of 5G technology in the domain of production and contribution of TV content. Primary focus lies on nomadic production settings using smartphones as a production means. The starting point was testing the setup on the SWR premises in Baden-Baden. After this, several trials were carried out under real-world conditions. The target is to use 5G technology for nomadic live TV productions. A first occasion to do so was at the beginning of December 2023.

10.2 Setup

The setup varies depending on the circumstances of the nomadic event. Different types of cameras are used including professional high-end cameras, PTZ cameras and smartphones. In the 5G Campusnetz project, the SWR engages with a single technology provider which is Smart Mobile Labs (SML) from Munich. The 5G network established is an NPN. Usage of public network components have been tested already for contribution (i.e., bundled SIMs). Nomadic use of the 5G equipment is enabled by means of a trailer provided by SML that carries the base station, mast and antenna, and all necessary hardware components. The focus of the trial is on enabling the use of 5G technology rather than carrying out measurements. As such it is a very hands-on project in close collaboration with the respective TV production teams.

10.3 Spectrum

All tests were carried out within the spectrum that the German regulator, BNetzA, makes available in the C-band, i.e., 3.7-3.8 GHz. This spectrum is reserved for use on the premises of companies under given conditions. Use of the spectrum under nomadic conditions calls for dedicated frequency assignment for short-term use, which has to be applied for some time before the event.

10.4 Results

As mentioned, the SWR project is not initially about assessing KPIs of 5G technology for production and contribution of TV content. Rather, the objective is to try to integrate it into daily operation. A major outcome is certainly that production colleagues started to see the potential benefits of 5G for their work. There are ongoing discussions to integrate 5G technology in the upcoming renovation of the TV production studios of SWR in Baden-Baden.

10.5 Next steps

As mentioned above, it is planned to use the 5G equipment as soon as possible for Live TV productions. Moreover, there are discussions to consider 5G technology as part of the renovation of TV studios in Baden-Baden.

11. TV 2 Denmark – GO’ studio live from Tivoli

General Information

Name of trial(s):	GO’ studio live from Tivoli – SONY PoC
Name of the organisation:	TV 2 Denmark A/S
Contact person:	Morten Brandstrup (mobr@tv2.dk)
Dates and places of the trials:	1st November 2023, Tivoli, Copenhagen, Denmark



11.1 Goals

A proof of concept to prove an end-to-end production workflow in an on-air primetime talk show, with use of a Cumucore core, NodH RAN and Sony prototype ULL encoder.

In a further step forward in the use of 5G technology in live production, Danish public broadcaster TV 2, Sony Corporation, Sony subsidiary Nevion, Radio Access Network (RAN) software specialist Node-H, and Cumucore, a leading non-public network (NPN) provider have conducted a successful proof of concept (PoC) using the wireless technology in a live studio environment. The test demonstrated that 5G connectivity could potentially be used in any live production, simplifying the logistics and the cabling of the infrastructure.

On 1st November 2023, TV 2 evaluated the capabilities of the 5G technology during the production of the daily “Go’ aften Live” evening show, from its studio located in the Tivoli Gardens in central Copenhagen (Denmark). For that purpose, TV 2 installed two Sony 5G-enabled system cameras in addition to their usual wired studio cameras.

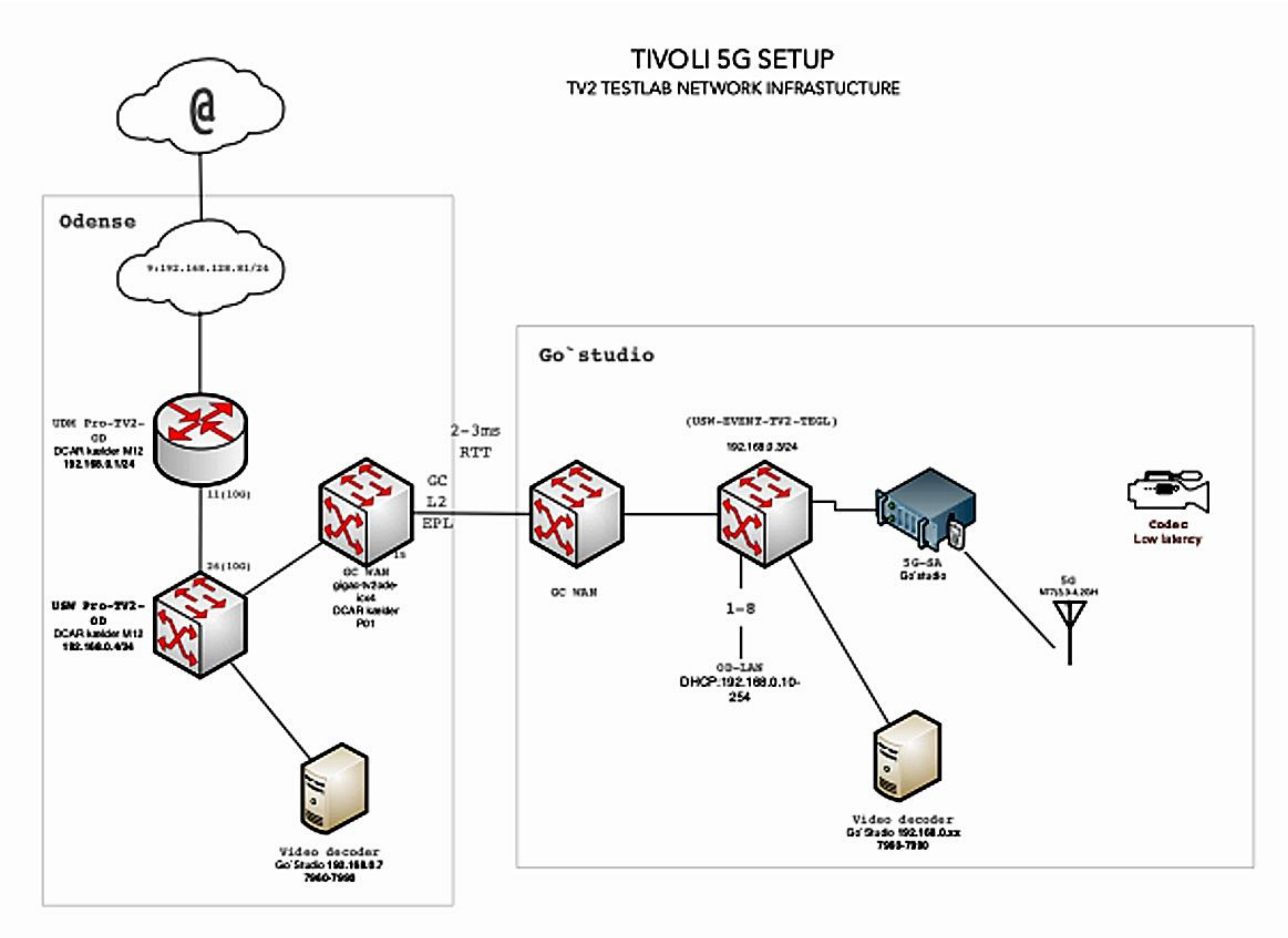
11.2 Setup

In the studio, an NPN was created, using Cucumore’s 5G Litecore technology, working in tandem with Node-H’s RAN.

Each camera was connected to the 5G network via a prototype of Sony’s recently announced CBK-RPU7 (an ultra-low latency HEVC 4K/HD remote production unit), and an Xperia™ 5G smartphone acting as a modem. The CBK-RPU7 ensures that video signals are efficiently compressed to make optimum use of the available 5G bandwidth, while matching the picture quality of the wired cameras. The media orchestration was provided by the Nevion VideoIPath platform, which ensured the broadcast signal was given priority on the 5G network.

During the TV 2 broadcast, the production team included pictures acquired over the 5G-enabled cameras, proving that the quality matched the high standard required for this prime-time live production.

Setup:



Partners:	TV 2, Sony Corporation, Nevion, Node-H*, and Cumucore
Type of network:	Standalone Non-Public Network
Network configuration:	5G SA NPN network
Type of equipment:	Two Sony 5G-enabled system cameras, Sony CBK-RPU7** (remote production unit), Sony Experia Smartphone, Cucumore 5G Litecore, Nevion VideoIPath platform.
Nomadic setup:	fixed location, indoor production studio
*http://www.node-h.com/en/solutions/5g_ran_software.php **https://pro.sony/ue_US/pdf/cbk-rpu7	

11.3 Spectrum

1. N77, 3810-3910 MHz, max 15 dBm / (5 MHz) eirp.
2. Temporary test licence.

11.4 Results

- PoC verification; Morten Brandstrup, Head of News Technology at TV 2 Denmark said: "Along with our production services provider, Boffins Technology, we were interested to see how the 5G technology could integrate into a live studio environment. We were very confident in the outcome of the test, but even we were surprised with the quality of the signals from the 5G-enabled cameras. For us this proof of concept opens the possibility of using 5G cameras in a wider context, including studio-based productions. This will add greatly to the flexibility of our production workflows".
- KPI measurements; 35 Mbit/s video, Latency approximately 150 ms glass-to-glass, jitter close to zero.
- PoC concept integrated into the main production and used in live broadcast, together with triax cabled studio camera.
- Full broadcast quality, no visual difference between camera signals.

11.5 Next steps

Continue test with Cumucore+node H setup. Distributed core/RAN

11.6 Further information

https://www.tvbeurope.com/live-production/denmarks-tv-2-trials-5g-in-a-live-studio-production

https://nevion.com/news/press-releases/tv2-denmark-5g-live/

https://www.sony.eu/presscentre/tv-2-denmark-teams-up-with-sony-nevion-node-h-and-cumucore-to-test-5g-in-a-live-studio-production

https://fr.techtribune.net/d2/smartphones/la-chaine-danoise-tv-2-teste-la-5g-dans-une-production-en-direct-en-studio/797234/

https://www.elektronikfokus.dk/tv2-og-sony-samarbejder-om-fremtidig-mulighed-for-brug-af-5g-til-tv-transmissioner/

Annex: References and recommended publications

EBU publications:

1 EBU TR056: '*5G For profession production and contribution*

3GPP documents:

2 3GPP TR 26.805: '*Study on Media Production over 5G NPN Systems*

3 3GPP TS 22.263: '*Service requirements for Video, Imaging and Audio for Professional Applications (VIAPA)*

4 3GPP TR 22.827: '*Study on Audio-Visual Service Production*

5G MAG documents (https://www.5g-mag.com):

5 *Non-Public 5G Networks for Content Production*

6 *Deploying stand-alone Non-Public 5G Networks for media production*

7 *5G NPNs for media production in collaboration with third-party networks*

8 *Towards a comprehensive 5G-based toolbox for live media production*

9 *Guidelines on registration and onboarding for media production equipment over 5G NPNs*

10 *Spectrum access for live media production using Non-Public Networks (NPNs)*

5G Records deliverables (https://www.5g-records.eu/):

11 D2.1 *5G regulatory framework for content production*

12 D2.2 *Business analysis*

IBC 2023 articles:

13 *5G Standalone Non-Public Networks: Modernising Wireless Production*

14 5G Jazz Jam Session – An experiment of combined arts