Linear Television Broadcasting over 5G Networks, Part 1: Spectrum Considerations

by **Dr. Les Sabel** (S-Comm Technologies); **Peter Walop** (Convergence Consulting Company)

ABSTRACT
This article addresses the spectrum demands for carrying linear TV services over 5G mobile networks.

It is important to note that this article focusses on the terrestrial delivery of *linear television services* over 5G networks. These linear television services are typically delivered by High-Power High-Tower (HPHT) networks, commonly referred to as terrestrial broadcasting networks, and are often Free-To-Air (FTA). The delivery of Video-On-Demand (VOD) services are not addressed in this article.

In an associated article of both authors, titled *Linear Television Broadcasting over 5G Networks, Part 2: Regulatory and Business Considerations*, having a supporting regulatory and licensing framework, as well as having a viable business case for 5G based broadcasting, are addressed.

INTRODUCTION

Renewed efforts from the telecom and broadcasting industry to deliver linear television services using mobile cellular technology networks have recently gained traction again. Dating back as far as the early 2000s, technologies such as DVB-H, MediaFlow, T-DMB and ATSC-M/H had limited business success. The capability to deliver linear television services over FeMBMS enabled LTE/5G networks, as defined in 3GPP releases 14/16 and labelled 5G Broadcast (5G BC), may be more promising. The definition of FeMBMS now includes additional 5G numerologies and significantly larger OFDM Guard Intervals to allow networks to operate in Single Frequency Network (SFN) modes.

Several experiments and studies on the structure and use of 5G BC have been carried out, such as those reported in documents including ETSI TS 103 720 and EN 302 296 and EBU documents TR054, TR063 and TR064. Although this article builds on the experiences gained, it focusses on the terrestrial delivery of *linear television services* over 5G based networks.

Preparations for the World Radio Conference of 2023 (WRC-23) are now well underway as the industry currently debates the possibility of migrating large parts of terrestrial television services to 5G networks. WRC-23 Agenda Item 1.5 addresses possible changes to the use of the 470 - 694 MHz band in ITU Region 1 to allow 5G service operation. The USA, in ITU Region 2, has cleared 84 MHz of digital television (DTV) spectrum in the UHF 600 MHz band for mobile use. It is noted that for ITU Region 3, the 600 MHz band is not being considered in the forthcoming WRC-23.

Given this background of new 5G technology developments and the global spectrum management agenda of WRC-23, this article addresses the spectrum demands for carrying linear TV services over 5G mobile networks.

SPECTRUM DEMANDS FOR TV OVER 5G NETWORKS

In this Part 1, we first examine what spectrum is needed to deliver linear or FTA television services, using unicast mode over 5G mobile networks. Secondly, we consider the alternative of delivering FTA services over dedicated 5G BC networks.

5G UNICAST DELIVERY

It is important to note that in this analysis of 5G unicast delivery we do not consider the needs of other traffic. Only the spectrum bandwidth that would be required for the carriage of FTA television services at peak hours is considered.

For calculating the spectrum demands for carrying FTA services over a 5G unicast network, we first model the FTA viewing situation, followed by defining the bitrate requirements for the various types of FTA service and model the spectral efficiency of 5G services. With these three sets of assumptions, we calculate the spectrum demands for the various scenarios.

VIEWING SITUATIONS

Assuming a large city population of 5 million, which requires approximately 1,000 mobile phone cells, implies that on average there are 5,000 people per cell, the major MNO's in Sydney Australia being examples.

Viewing of FTA services are not equal during a day and tends to peak in the morning and early evening when the daily news and current affairs programs are delivered, typically between 7 and 9 am and 5 and 7:30 pm in most countries. Hence, we need to calculate the traffic for these peak hours. Different viewing scenarios at these peak hours are compared, as defined in ***Table 1*** below. We have assumed an average household size of four people. With 5,000 people per cell this assumption results in 1,250 households per cell.

Viewing scenario	Household viewing situation	Percentage of Households with given viewing situation in each cell	Number of unicast streams per cell, at peak hour
1	4 people, each viewing a different FTA service, at peak hour.	100%, all households	5,000
2	4 people, all viewing the same FTA service, at peak hour	As above	1,250
3	As above	50%	625
4	As above	25%	312

Table 1: *Viewing scenarios*

FEATURE ARTICLE 2

BIT RATE REQUIREMENTS PER TYPE OF SERVICE

For determining the required bitrates per type of service, we need to select the applied video encoding standard. To date the highest efficiency video coding scheme used in digital broadcasting is H.265/High Efficiency Video Coding (HEVC) which is more efficient than the more commonly used H.264/Advanced Video Coding (AVC) scheme. H.264 is used in DVB-T while H.265 is used in DVB-T2 and ATSC-3.0. Recent developments in video coding have resulted in the H.266/Versatile Video Coding (VVC) standard which claims to reduce the required bitrate relative to H.265 by 40% to 50% for UHD and 8k resolutions [1] and slightly less around 30% for HD and SD. The VVC codec is currently being integrated into the DVB-T2 and ATSC 3.0 standards and is also gradually getting acceptance for streaming and video playback applications.

For setting the required bit rates, we use in this article the H.265/HEVC and H.266/VVC standards, noting that the latter does not have any commercial applications yet. ***Table 2*** shows the required bit rates per FTA service type for the two encoding standards.

Resolution		Bitrate (H.265) (Mbps)	Bitrate (H.266) (Mbps)
UHD (4K)	3840 x 2160	16	8
FHD (2K)	1920 x 1080	8	4
HD (HD ready)	1280 x 720	4	2
SD	720 x 576	2	1

Table 2: *Required bit rates per FTA service type*

For the values in ***Table 2*** we have used average bit rate values for delivering the various television services to TV screen sizes greater than 48" [2]. It is noted that the different providers use varying bitrates, as the required bit rates are not only dependent on the picture resolution but are also dependent on the number of frames per second, HDR/colour method and encoding technology applied.

5G SPECTRAL EFFICIENCY

We study the bandwidth requirements of the average cell considering different modulation orders. The details of 5G spectral efficiency provided by different modulation and Forward Error Correction (FEC) coding are defined in [3] table 5.1.3.1 and summarised in ***Table 3*** below, using the mean FEC rate for each modulation order.

Modulation	Spectral efficiency using mean FEC rate (bps/Hz)
QPSK	0.71
16QAM	2.02
64QAM	3.92
256QAM	6.37

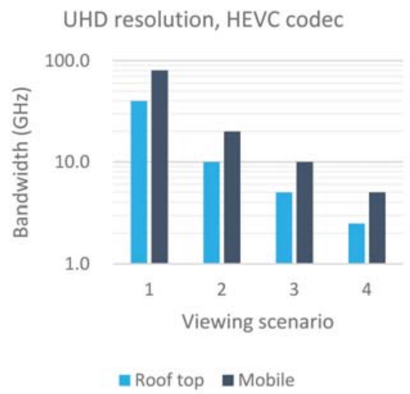
Table 3: *Modulation orders and spectral efficiency (non-MIMO)*

We find in the ITU 5G evaluation report [4] that under realistic conditions for mobility that the spectral efficiency values will generally be lower than the maximum values available. The values as provided in [4] do not include any overheads which may reduce the video payload capacity. For our estimation of the required bandwidth for carrying FTA services, we use two scenarios. For the first case we assume a roof-top antenna and a high spectral efficiency of 6 bps/Hz which corresponds to using 256 QAM modulation and a code rate of 0.73 [3] and which is very close to the 0.75 code rate used in DVB-T2. For the second case we consider the mobile and indoor scenario assuming a more robust spectral efficiency of 3 bps/Hz which corresponds to 64 QAM and a code rate of 0.5 [3]. We do not include any additional gain which may be provided by Multiple Input Multiple Output (MIMO) techniques due to the difficulty of implementation in the sub-1 GHz band. Finally, we use a frequency reuse ratio of 3 as the standard case for macro/micro cells in a cellular network.

CALCULATION RESULTS

The resulting requirements for the average bandwidth (in GHz) per network cell, under the different viewing scenarios (numbered 1 to 4) and FTA service types (UHD and HD), are shown in ***Figure 1*** for the current H.265/HEVC codec and in ***Figure 2*** for the new H.266/VVC codec.

Figure 1: *Total bandwidth (in GHz) per cell for unicast delivery using H.265/HEVC video codin*



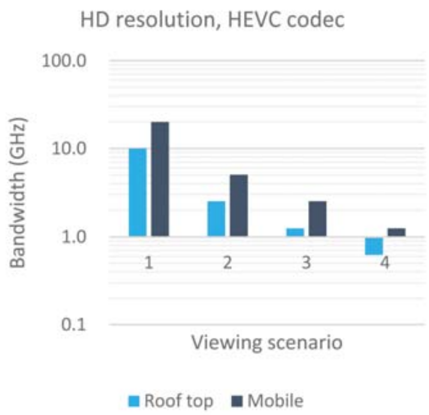
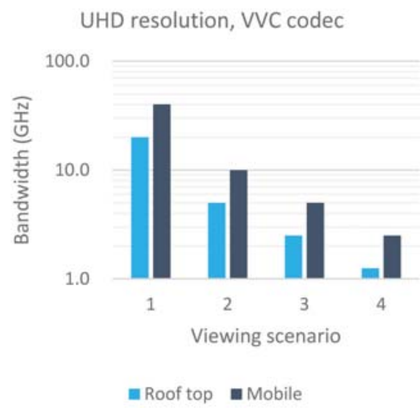
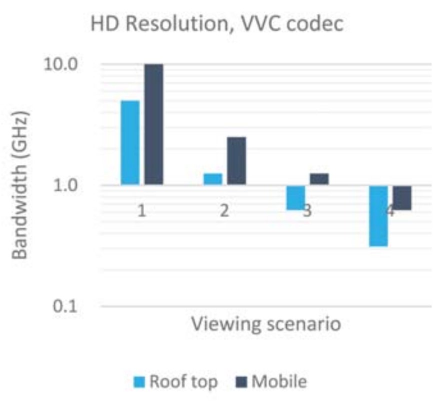


Figure 2: *Total bandwidth (in GHz) per cell for unicast delivery using H.266/VVC video coding*





From the left graph in ***Figure 1***, for delivering UHD services under viewing scenario one when using the current HEVC video codec, we see that the required bandwidth is 40 and 80 GHz respectively for rooftop and mobile reception, an amount of spectrum that even millimetre wave bands could not support. The right graph in ***Figure 1*** shows that for viewing scenario three and delivering HD services, the bandwidth requirement is 1.3 and 2.5 GHz respectively for rooftop and mobile reception. Such a spectrum demand is also highly unlikely to be supported, even by using all the sub-6 GHz frequency bands.

Given these high bandwidth requirements we now examine the ability of the three individual mobile frequency bands (the sub-1 GHz band, mid bands (1 to 5 GHz) and millimetre wave bands (typically above 20 GHz)) to deliver FTA services.

For the sub-1 GHz, 5G can cover cells of 2 km radius. There is approximately 250 MHz of paired spectrum, or 125 MHz of downlink spectrum in the range from 600 MHz to 1 GHz (country dependent). Sub-1 GHz spectrum is very valuable for use in macro cells and rural situations. The analysis shows that even for the most lenient case of viewing scenario four and the use of H.266/VVC codec for HD resolution video, the sub-1 GHz spectrum is unable to support the demand of 300 and 600 MHz respectively for rooftop and mobile reception.

Alternatively, the lower mid-band frequencies may also be able to cover cells with 2 km radius and in this lower mid-band range there is around 0.5 GHz of downlink spectrum available, and then a further 1 to 1.5 GHz in the upper mid-band range. However, it is unlikely that those frequencies will be able to provide in-building support for high bitrate services near the edge of the cell. In both cases (below 1 GHz and mid-band) there is insufficient spectrum to support all UHD services, even with limited viewing like in viewing scenario 4. It is likely that there will be a mix of UHD and HD/SD in various use cases including rooftop and mobile reception, however the resulting demand at peak hours is likely to exceed the bandwidth availability in the combined sub-1 GHz and mid-range bands, even when excluding other traffic.

The high-band frequencies, typically above 20 GHz and up to 70 GHz, have substantially more spectrum. In total up to 18 GHz could be made available in this frequency range over time. These frequencies however suffer from significantly higher losses with typical cell radius of less than 500m with reasonable traffic loads. In other words, the use of the high-band frequencies is likely to require around 20 sites within the 2 km cell radius.

In summary, even with higher operating frequencies and the latest encoding technologies 5G unicast will struggle to deliver all FTA services and the cost to MNOs will be enormous, let alone the unsightly impact of the significant increase in antenna sites. Furthermore, the rollout of that many sites will take many years, if it is at all viable.

5G BROADCAST DELIVERY

The 3GPP introduced changes to the 5G BC system in Releases 14/16 which provide near equivalence in spectral efficiency of 5G BC and Digital Terrestrial Television Broadcasting (DTTB) systems such as DVB-T2/ATSC 3.0. In terms of best-case reception, such as rooftop reception, both systems are theoretically close to the Shannon limit.

We note that when 5G BC is consumed in a mobile, indoor and Non Line Of Sight (NLOS) reception areas, which applies for most mobile use cases, then the usable Modulation and Coding Scheme (MCS) combinations moves to the lower end of the spectral efficiency.

Given transmission power allocation to achieve coverage using rooftop reception, the area which would receive viable mobile coverage is vastly decreased by to additional losses due to receiver height, antenna gain, building entry losses and mobility as 5G BC does not currently include any time interleaving.

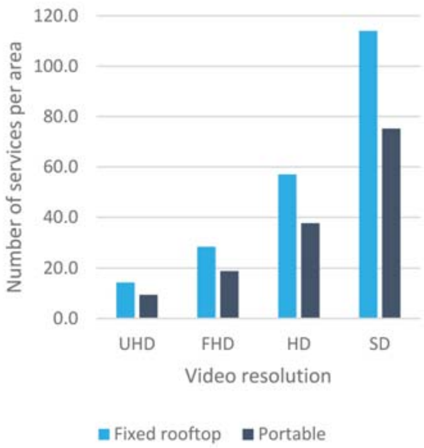
These DTTB systems are commonly deployed in the UHF band. In Europe the band 470 - 698 MHz (228 MHz) is allocated to broadcasting services, whereas in the USA the band 470 - 608 MHz (138 MHz) is in use for terrestrial broadcasting as the 600MHz spectrum was previously allocated to mobile services. A 5G BC network would operate in the same UHF bands.

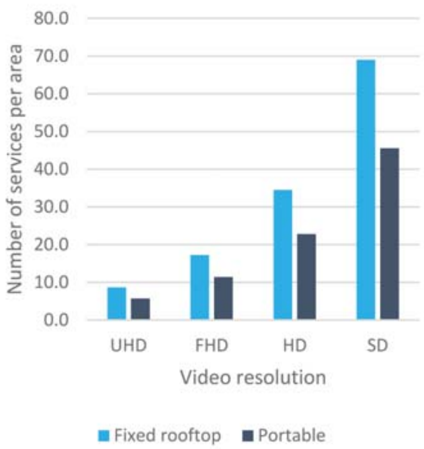
With 5G unicast the number of simultaneous streaming sessions (at peak hour) drives the spectrum needed, independent from the number of television services. In contrast, with 5G (or DTT) broadcast delivery the number of television services is limited by the amount of spectrum that is available. We can estimate the maximum number of services which can be provided in the current spectrum using a few basic assumptions.

From DTTB network planning in the various countries, we know that the frequency re-use factor ranges between 3 to 6 for deploying national services for achieving 95% population coverage. These frequency re-use factors can be achieved by deploying as much as possible Single Frequency Networks (SFNs). We use 5 as a mean frequency reuse factor value as suggested in [5], this gives us a maximum bandwidth of 45.6 MHz (228 MHz/5) per area in Europe and 27.6 MHz (138 MHz/5) in the USA.

Using the numbers in [6] table 5 for DVB-T2 spectral efficiency we obtain the values for the average number of services available in an area for the case of fixed rooftop antenna (256QAM) and portable receivers (64QAM) as shown in ***Figure 3*** for Europe and the USA for the case of HEVC coding while ***Figure 4*** covers the case of VVC coding.

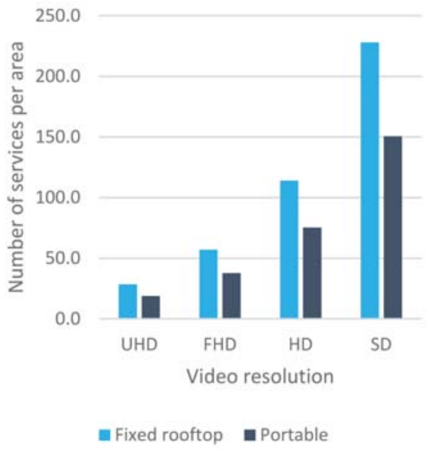
Figure 3: *Average number of services per area when using the H.265/HEVC codec – left = Europe, right = USA*

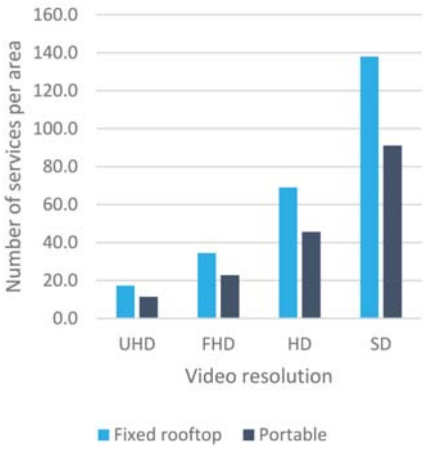




FEATURE ARTICLE 2

Figure 4*: Average number of services per area when using the H.266/VVC codec – left = Europe, right = USA*





When using HEVC video coding, ***Figure 3*** shows that for Europe the number of UHD services will be 14 if rooftop reception is assumed, and 9 if portable reception is assumed, noting that portable indoor reception may be difficult in some situations due to building entry propagation losses. In contrast the number of UHD increases to 28 and 18 for the future case of VVC, as shown in ***Figure 4***. The situation in the USA is similar but scaled to lower values as less bandwidth is available.

Given that there are already significant numbers of FTA services in Europe and the USA, where 2nd generation DTTB is available, the options for introducing UHD services are limited because a single UHD transmission will require approximately 8 times more bitrate as a SD service. As the 2nd generation transmission standards are already close to the Shannon limit, any technical improvement for carrying more UHD services will have to come from better video coding.

While it may be possible to improve video coding efficiency beyond VVC, the introduction of a further codec will take considerable time considering that H.266/VVC is still in the implementation process and no receivers are commercially available yet.

While it is likely that there will be some limited UHD services offered for prime content such as international sports like the Olympic Games it is also likely that there will be an ongoing mix of HD and SD services to support different service content types. As television services migrate to UHD and demand increases for these service types even with the widespread use of H.266/VVC, it is likely that programming of films and TV shows will increasingly be consumed through VOD streaming using both fixed and mobile networks. This supports the assertion that FTA TV will increasingly focus on news, sports and live events.

CONCLUSIONS

This article demonstrated that delivering all FTA services over 5G unicast is not a feasible option as such a solution would require significantly more than the available spectrum. FTA services delivered over 5G BC is technically not different from DTTB delivery in terms of spectrum efficiency, as both solutions are OFDM based and near the Shannon limit.

Hence, 5G based broadcasting should not be viewed as a DTTB replacement. A better model would be to combine DTTB broadcasting with 5G network services, whereby DTTB would focus on FTA service delivery, albeit with a smaller number of services in UHD quality. 5G networks would continue to deliver VOD services, whereby 5G BC can be deployed as an advanced traffic management tool to further increase the capacity of mobile networks.

REFERENCES

[1] https://www.theverge.com/2020/7/7/21316525/fraunhofer-vvc-video-codec-streaming-4k-video-cost-file-size-standards
[2] Li et al, “AVC, HEVC, VP9, AVS2 or AV1? – A Comparative Study of State-of-the-art Video Encoders on 4K Videos”, University of Waterloo, 2020
[3] 3GPP TS 38.214 V16.7.0 (2021-09); 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for data (Release 16)
[4] ITU report 5G-IA-Final-Evaluation-Report-3GPP-1,”FINAL EVALUATION REPORT FROM THE 5G INFRASTRUCTURE ASSOCIATION ON IMT-2020 PROPOSALS IMT-2020/ 14, 15, 16, PARTS OF 17”, 8 February 2020
[5] Brugger, R., Schertz, A., “TV Distribution via Cellular Networks: Spectrum Consumption”, EBU Tech Rev Q2/2014, Geneva, 2014
[6] EBU TR029, DVB-T2 single frequency networks and spectrum efficiency, November 2014

AUTHORS

Dr Les Sabel, Chair, WorldDAB Asia Pacific Technical Group, and S-Comm Technologies WorldDAB

Les has over 30 years of experience in communications systems, including broadcast digital radio (DAB/DAB+ and DRM), mobile communications, wireless broadband and satellite communications. Les founded S-Comm Technologies Pty. Ltd. in 2008 to work with the radio industry on DAB+ digital radio. S-Comm provides independent engineering consultancy to WorldDAB, the ITU and broadcasters, regulators, network operators and equipment suppliers in Australia, South East Asia and around the globe.

Peter Walop, Executive Partner, Convergence Consultant Company

Peter Walop has over 25 years of working experience in the broadcasting and telecommunications markets. As a consultant, Peter assisted telecom operators, broadcasters, and regulators with the introduction of telecom and digital broadcasting services in a wide range of countries, including Angola, Belgium, Bhutan, Burundi, Cambodia, Denmark, Ethiopia, France, the Gambia, Germany, India, Jamaica, Japan, Luxembourg, Malaysia, The Netherlands, Norway, Rwanda, Serbia, Spain, Sweden, Switzerland, Thailand, Uganda, and Vietnam. ■