ATSC 3.0 Broadcast 5G Unicast Heterogeneous Network Converged Services Starting Release 16

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***Abstract*—In this paper, the ATSC 3.0 broadcast Radio Access Technology (RAT) is aligned with 3GPP 5G NR RAT in the context of 5G convergence starting in Release 16. The 5G system architecture release 16 includes a new 5G physical layer known as 5G NR "New Radio" and a "Cloud Native" 5G Core (5GC) using cloud computing. The 5GC is agnostic to the type of radio access technology used and is enabler of many types of convergence. A novel shared multi-tenant broadcast core network architecture designed to interwork with 5GC is discussed. With the 3GPP 5G NR unicast and Non-3GPP ATSC 3.0 broadcast synergistically aligned using methods of Release 16. This includes using 3GPP Access Traffic Steering, Switching, Splitting (ATSSS) and a multi-radio dual simultaneous connected User Equipment (UE). This aligns ATSC 3.0, the first forward looking (non-backward-compatible) native IP OFDM broadcast standard, with 3GPP LTE/5G unicast as a converged 5G vertical. The proposed method and architecture are orthogonal to LTE broadcast Release 16 and is synergistic to 5G NR mixed-mode multicast unicast in future.**

***Index Terms*—5G core, 5G NR, ATSC 3.0, broadcast core, ATSSS, heterogeneous network convergence.**

I. Introduction

THE FUTURE of wireless systems operational architectures such as in 3GPP 5G is profoundly changing by the adoption of new radio technologies driven by virtualized core networks using cloud computing. The 5G architecture in Release 16 satisfies requests for each service use case by orchestrating the chaining together of virtual network functions to create independent services as end-to-end logical slices of the physical 5G network and this paradigm shift is termed 5G network slicing.

The current USA broadcast regulatory environment permits broadcasters to voluntarily innovate using the ATSC 3.0 physical layer standard with their spectrum for new services including mobile. It permits shared use of licensed broadcast spectrum and transmission infrastructure. Therefore, a new multi-radio dual connected user equipment (UE) using 3GPP 5G NR and Non-3GPP ATSC 3.0 broadcast synergistically aligned is proposed in this paper. 3GPP has defined a 5G NR (New Radio) [1] a cloud-native Service Based Architecture (SBA) 5G Core (5GC) [2], [3], [4].

The 5G NR operates in multiple 3GPP spectrum bands and uses 3GPP and Non-3GPP RAT with dual connected UE for the service requirements of 5G in Release 16.

Multi-band, multi-RAT dual connected UE using both 3GPP and Non-3GPP RAT is specified in 3GPP TS 22.261 [5, Sec. 6.3]. A new Non-3GPP ATSC 3.0 broadcast RAT is proposed that is synergistically aligned to 5G NR by using the existing methodology specified in Release 16. This can bring valuable low-band spectrum into play that can offer new aligned broadcast 5G converged use cases.

The ATSC 3.0 broadcast standard [6], [7], [8] is the first and only forward looking (non-backward-compatible) OFDM broadcast physical layer standard using a native IP transport, designed for extensibility and future alignment with the 4G LTE physical layer. The ATSC 3.0 physical layer is now also aligned to 5G NR physical layer frame and L1 signaling to enhance 5G convergence while using 3GPP ATSSS [12], [13], [24].

This paper proposes innovative change by aligning Non-3GPP ATSC 3.0 broadcast RAT with 3GPP 5G NR unicast RAT. The unicast RAT and broadcast RAT are first each optimized for their diverse radio physics environments and received using a dual simultaneously connected UE.

The current 3GPP spectrum bands for 5G are divided into low-band sub-1 GHz, mid-band 1- 6 GHz and high-band above 6 GHz. The low-band spectrum physics, enables operator both larger cell coverage and deeper in-building penetration, etc. The mid-band offers reasonable coverage and good capacity with bandwidths up to 100MHz. The high-band with bandwidths up to 400MHz and with massive MIMO and beamforming can increase capacity and efficiency. However, the disadvantage to high-band is reduced cell size and the signal's susceptibility of being blocked by objects in the environment.

The clear premise is that spectrum is not fungible given radio physics. Therefore, the 5G NR system architecture in Release 16 is designed to support the synergy of a multi-band, multi-RAT heterogeneous network (HetNet) architecture and a dual simultaneously connected UE.

The remainder of this paper is structured as follows: Section II describes several 5G Release 16 deployment system architecture options analogous to proposed broadcast 5G convergence system architecture; Section III compares some relevant 5G NR and ATSC 3.0 RAT aspects; Section IV describes the proposed ATSC 3.0 RAT alignment with 5G; Section V introduces the 5G Core in the context of supporting 3GPP and

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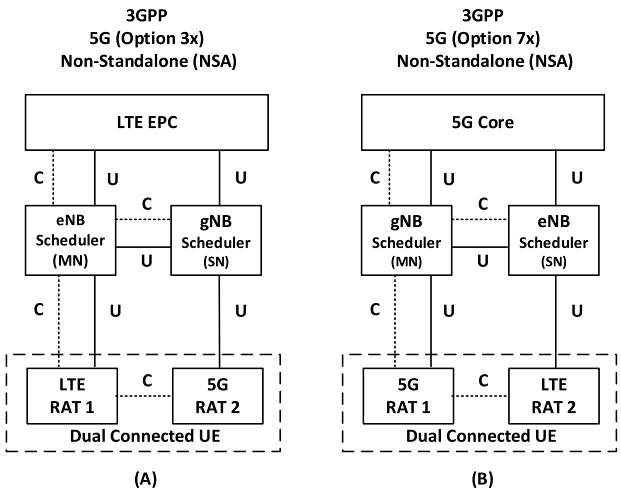

Fig. 1. (A) 5G NSA LTE as Anchor, (B) 5G NSA 5G as Anchor.

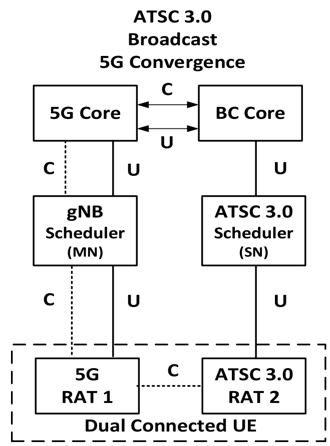

Fig. 2. Broadcast 5G convergence architecture proposed.

Non-3GPP access; Section VI introduces a proposed Broadcast Core interworking with 5G Core; Section VII describes example use case USA of shared Broadcast Core and platform for 5G Convergence; Section VIII provides conclusions and future planned research.

II. Several 5G Release 16 Deployment Options

Figure 1 depicts a high-level view of several 5G Non-Stand Alone (NSA) architecture deployment options. These are briefly introduced for context and to improve initial understanding of the methodology in Release 16. These options have similarities to the proposed aligned broadcast 5G convergence system architecture shown in Figure 2.

Figure 1 (a) is NSA option 3x, a popular choice for early deployment of 5G NR for achieving higher data capacity. This 5G deployment option is termed Non-Stand Alone because the 5GC is not deployed, but 5G depends on LTE which is termed an anchor. In option 3x, the MNO uses existing 4G LTE base station (eNB) and Evolved Packet Core (EPC) as anchors for 5G NR and multi-RAT dual connected UE in Release 16.

Figure 1 (a) the 4G LTE eNB is termed Master Node (MN) or cell and uses existing low-band spectrum. The LTE EPC serves as an anchor to support the 5G gNB Secondary Node (SN) or cell in mid-high band spectrum for higher data capacity.

An essential detail of Figure 1 (a) is that both the eNB and gNB has an independent OFDM MAC layer scheduler based on a specific standard 4G LTE, 5G NR, etc. These schedulers then allocate OFDM resources in the normative manner expected by UE. Some details Figure 1 (a) are that the eNB MN and LTE RAT 1 both have user plane (U) and control plane (C) data from EPC shown. The EPC and eNB then serve as an anchor for the control plane (C) of 5G RAT2 as shown between LTE RAT 1 and 5G RAT 2 in the UE. The gNB is a SN and only has (U) shown provided either from the EPC to RAT 2 or via an interface shown between the eNB and gNB to 5G RAT 2.

An advantage of using this HetNet with 5G NR in high-band spectrum and given the knowledge that the Up Link (UL) from 5G UE is the limiting factor for 5G NR coverage. In NSA option 3x, the EPC can seamlessly schedule UE to use the LTE eNB for the 5G UL on the low-band spectrum. This effectively extends the 5G NR coverage area using the physics attributes inherent in the low band spectrum.

Another HetNet attribute used to mitigate early 5G NR deployment in the mid-high band is by improving the continuity of service perceived by the consumer. When the dual connected UE roams outside the small cell 5G NR coverage, LTE 4G can continue to provide seamless service using larger LTE 4G low-band coverage area in a way that is agnostic to the consumer.

In Figure 1(b) NSA option 7x is shown. 5GC is used instead of EPC supporting 5G NR for high data capacity. Moreover, the 5GC cloud computing architecture is required to orchestrate all new 5G use cases and verticals, with high data capacity and needed intelligence including on the edge of the network for low latency uses cases and 5G network slicing. In Figure 1 (b) the roles of MN and SN are reversed for the eNB and the gNB and the 5GC and gNB are used as an anchor for 4G LTE RAT 2. Again, the diverse HetNet attributes are used to improve service quality in a way agnostic to the consumer.

Figure 2 is high-level view of the proposed broadcast 5G convergence architecture using methodologies of Release 16 in this paper. In this proposed HetNet architecture, the dual connected UE has 3GPP 5G unicast RAT 1 and Non-3GPP broadcast RAT 2. The ATSC 3.0 base station is SN with (U) only from broadcast core (BC) network. The 5G RAT 1 has both (U) and (C) from the gNB as MN, and 5GC. The 5GC and the BC user planes (U) and control planes (C) interwork using the interfaces shown. The ATSC 3.0 broadcast RAT 2 uses the gNB MN and 5GC as anchor for (C) and Uplink (UL) in this converged architecture which is discussed in more detail in Section VII.

III. 5G NR and ATSC 3.0 RAT Aspects

The diverse nature of unicast and broadcast physics when acknowledged and accepted can be synergistically leveraged as a net positive for efficiency, performance and new use cases in 5G heterogeneous networks using Release 16 methodology.

The central defining distinction between the 5G unicast design philosophy compared to ATSC 3.0 broadcast design philosophy is that 5G unicast has both a downlink and return channel uplink and heavily depends on using adaptive modulation coding scheme (MCS) and error recovery protocols. The 5G unicast scheduler receives reports on channel conditions at UE. The 5G unicast scheduler then selects modulation coding scheme (MCS) and OFDM sub-carriers or resource blocks with best channel conditions at UE. Moreover, MCS is selected for efficiency, knowing availability of adaptive MCS feedback UE and L2 layer MAC, RLC, PDCP protocols that offer re-transmission of uncorrected errors at UE.

Also, a relevant subject is the legacy 3GPP method used to combine broadcast OFDM resources into some sub-frames and unicast OFDM resources in other sub-frames of a shared 10ms unicast frame to introduce broadcast services. The same general approach is now and termed "Further evolved Multimedia Broadcast Multicast Service" (FeMBMS) and is used LTE broadcast in Release 16 with focus mostly on fixed broadcast television services. There is also a new 5G NR mixed-mode multicast unicast in 10ms 5G NR frames for the future [25]. These are both orthogonal to the method disclosed in this paper.

The LTE legacy method used to introduce broadcast services has deep rooted constraints. The first, is by not respecting the diverse physics of unicast and broadcast. Second, is the time multiplexing of both unicast and broadcast OFDM resources in a shared 10ms unicast frame optimized for only unicast. This results in a broadcast RAT lacking essential time diversity and efficiency. The unicast design philosophy views time diversity as adding latency and is not valued. However, using broadcast design philosophy where latency is not a primary constraint, time diversity greatly boosts performance and efficiency.

The ATSC 3.0 broadcast design goals are very different, understanding that the emitted signal purpose is to be received by many UE simultaneously without knowledge of channel conditions at any UE. The design of the ATSC 3.0 RAT uses an optimized Low-Density Parity Check (LDPC) and Non-uniform QAM (NU-QAM) constellations resulting in spectral efficiency that closely approaches the Shannon limit [9].

Additionally, ATSC 3.0 physical layer design philosophy offers multiple forms of diversity to improve performance and efficiency by helping to mitigate impulse noise and mobile fading channels, etc. The ATSC 3.0 diversity domains include:

A. Frequency domain
B. Time domain
C. Power domain (LDM)
D. Transmitter spatial domain
E. Channel Bonding (frequency domain)
F. UE antennas SISO spatial diversity (MRC)

(A) First, frequency diversity is achieved directly at the physical OFDM symbol by the sub-carriers carrying content data being interleaved across the entire channel bandwidth before emission with the inverse process applied at the UE.

(B) Next, time domain diversity is applied to the output cells of the LDPC non-uniform constellation block. These cells represent user plane IP data flows and are termed a physical layer pipe (PLP). These PLP cells are time interleaved to a depth of either: 50ms, 100ms, 200ms and then use dispersed PLP mapping into non-contiguous resource blocks across the symbols of a sub-frame. The broadcast frame size is selectable from 50ms-5000ms and with the dispersed PLP mapping provides additional time diversity by spreading the already time interleaved PLP cells out further in time in the sub-frame to improve impulse noise and the mobile fading channel performance. For example, note that in [10], [22], the mobile broadcasts show irrefutable improvements using time diversity for ATSC 3.0 mobile fading performance and efficiency.

(C) Transmitter spatial diversity is termed a single frequency network has multiple synchronized coherent broadcast transmitter sites emitting identical signals that are received from different spatial directions at the UE. This spatial diversity helps to mitigate obstructions (shadowing) in the propagation path and fading at UE receive antenna. These multiple coherent signals are then combined for gain at UE and are a major factor in the increased broadcast performance and efficiency.

(D) Non-Orthogonal Multiple Access (NOMA) in the power domain is termed Layer Division Multiplexing (LDM) in ATSC 3.0 [11]. This offers another domain with many use cases including combined unicast and broadcast services [21].

(E) ATSC 3.0 channel bonding uses separate carriers to either increase capacity similar to 4G/5G carrier-aggregation. Another option is bonding two synchronized carriers that are time multiplexed on a cell-by-cell (sub-carrier) basis for increased robustness via frequency diversity across non-contiguous carriers bonded in the broadcast band.

(F) For ATSC 3.0 SISO UE antenna diversity using Maximum Ratio Combining MRC is beneficial and efficient.

IV. ATSC 3.0 RAT CONVERGENCE 5G ALIGNMENT

The ATSC 3.0 specialist group TG3/S32 designed the RAT to be flexible and extensible, an essential ATSC 3.0 system requirement. The OFDM numerology is defined by:

$$\Delta\text{F (Hz)} = \frac{\text{Fs (Hz)}}{\text{IFFT (size)}} \quad (1)$$

where ΔF is sub-carrier spacing (Hz), and Fs is OFDM sampling frequency (Hz). The Fs (Hz) was carefully selected for ATSC 3.0 RAT so as not to preclude future alignment to the 3GPP RAT. This was technically assured by calculated selection of the ATSC 3.0 sampling frequency Fs:

$$\text{Fs} := [\text{N}] \times 384{,}000 \text{ Hz} \quad (2)$$

The factor 384,000 relates to WCDMA chip rate and was important in 4G LTE for compatibility reasons. The same Fs = [N] x 384,000 Hz (2) is used in ATSC 3.0, 4G LTE and 5G NR.

Table I is a consolidated view of the OFDM numerology in standards: 4G LTE, 5G NR and ATSC 3.0 respectfully and shows the value [N] selected and some OFDM parameters for comparison.

In ATSC 3.0 standard the value [N] is signaled to UE using 7 bits in the A/321 L1 signaling in each frame. This ensures extensible OFDM numerology for future frames designed for

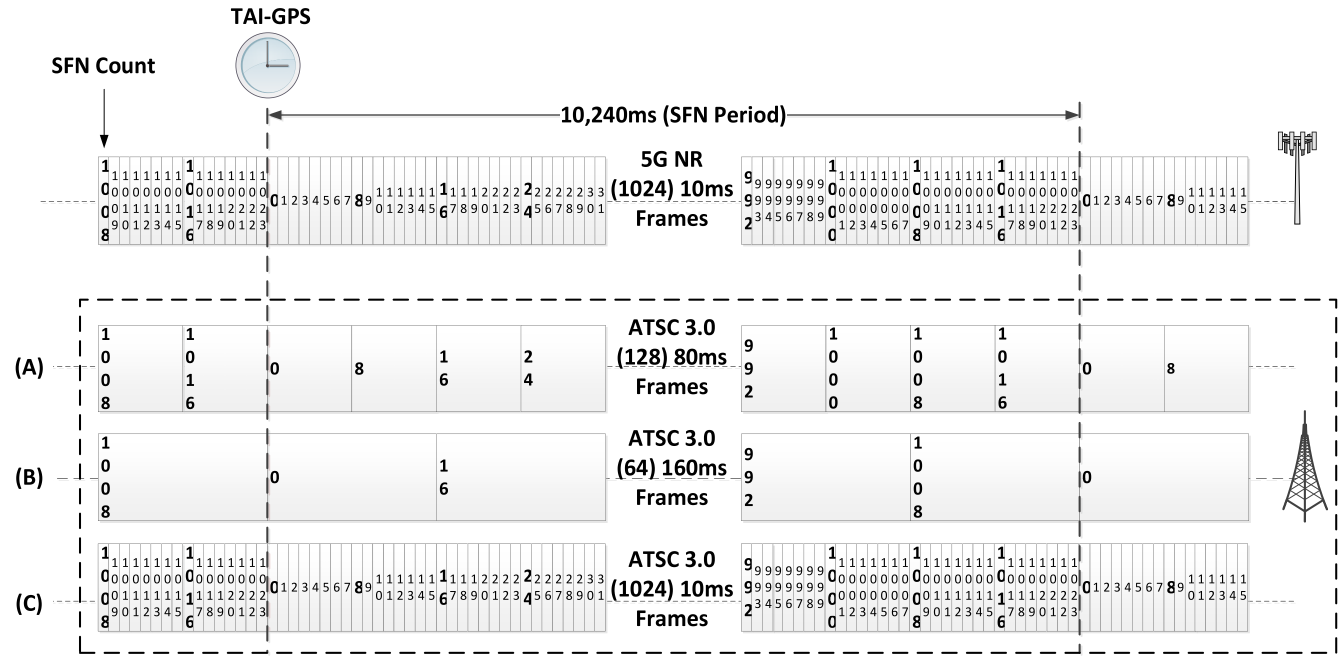

Fig. 3. ATSC 3.0 Frame Lengths (A) 80ms, (B) 160ms, (C) 10ms Time Aligned 5G NR 10ms Frames and Synchronized SFN counts.

TABLE I
CONSOLIDATED VIEW OFDM NUMEROLOGY LTE 4G, 5G NR, ATSC 3.0

Standard	Value [N]	Fs: MHz	IFFT	ΔF (Hz)	Tu (μs)	CP (μs)
LTE 4G	80	30.72	2048	15,000	~66.7	~4.7
5G NR	160	61.44	4096	15,000	~66.7	~4.7
5G NR	320	122.88	4096	30,000	~33.3	~2.3
5G NR	640	245.76	4096	60,000	~16.7	~1.2
5G NR	1280	491.52	4096	120,000	~8.33	~0.59
5G NR	2560	983.04	4096	240,000	~4.17	~0.29
ATSC 3.0	18	6.912	8192, 16384, 32768	843, 421, 210	~1186, 2375, 4761	~27 | 703
ATSC 3.0	21	8.064	8192, 16384, 32768	984, 492, 246	~1016, 2032, 4065	~23 | 603
ATSC 3.0	23	9.216	8192, 16384, 32768	1125, 562, 281	~888, 1779, 3558	~20 | 527

new specific use cases such as mobile or IoT, etc. The ATSC 3.0 RAT is designed to time multiplex different frames with different OFDM numerology and using L1 signaling so that UE gracefully ignores frames it is not capable of receiving.

In this paper, this related numerology is used as a basis to time align ATSC 3.0 frames to 5G NR unicast frames emitted at air interfaces of respective downlink antennas using the TAI reference clock. Also, the L1 signaling in the ATSC 3.0 frame has a System Frame Number (SFN) count phase locked to the SFN count in 5G NR unicast L1 signaling and these are both available at dual connected UE.

In 5G NR, the SFN count is based on 10-bit mod 1024 counter incremented with every 10ms frame. The SFN count wraps to zero every 1024 (frames) × 10ms = 10,240ms.

In ATSC 3.0, the frame length is selectable 50ms to 5000ms. Then, to enable 5G NR alignment, the ATSC 3.0 frame length is selected ensuring an integer number ATSC 3.0 frames occur in the 10,240ms SFN count period using:

$$\text{Frame Length} = \frac{1024}{2^N} x10ms[\text{N} = 2, 3, 4, 5, 6, 7, 8, 9, 10] \tag{3}$$

This results in the possible aligned ATSC 3.0 frame lengths: 10ms, 20ms, 40ms, 80ms, 160ms, 320ms, 640ms, 1280ms, 2560ms, with 1024, 512, 256, 128, 64, 32, 16, 8, 4, or 2 ATSC frames respectively in the 10,240ms SFN count period.

Figure 3 shows an example of time alignment of 10ms, 80ms, and 160ms ATSC 3.0 frames to 5G NR 10ms frames and with all L1 signaling SFN counts phased locked.

Then, to first establish and or then maintain frame alignment and synchronized SFN counts requires use of a TAI GPS reference clock shown. The synchronization algorithm uses GPS epoch 1980-01-06 at midnight UTC. The GPS epoch defines the instant that the first 5G NR and ATSC 3.0 frame were emitted antenna air interfaces with SFN counts equal to zero. To calculate SFN count at any instance in the future use:

$$\text{SFN count} = \text{GPS seconds} \times 100 \text{ mod}1024 \tag{4}$$

Then GPS seconds since epoch available from a GPS receiver x 100 converts seconds to 10ms increments, then mod 1024 establishes phase of SFN count (0-1023) at any instance and at any node in respective networks with GPS available.

The frame length (3) selection can be changed seamlessly on 10,240ms boundaries when using either 5G NR Time Division Duplex TDD or Frequency Division Duplex FDD with TDD used more in 3GPP mid-high band spectrum, and once the alignment is established, it will not drift using TAI reference.

Table II shows one example of future extended numerology using (1) and values [N] selected to optimize for mobile broadcast 5G convergence to be discussed in Section VII.

Table II shows some relevant frequency ranges of 200 – 700 MHz and BW 5-20MHz in context of example to be

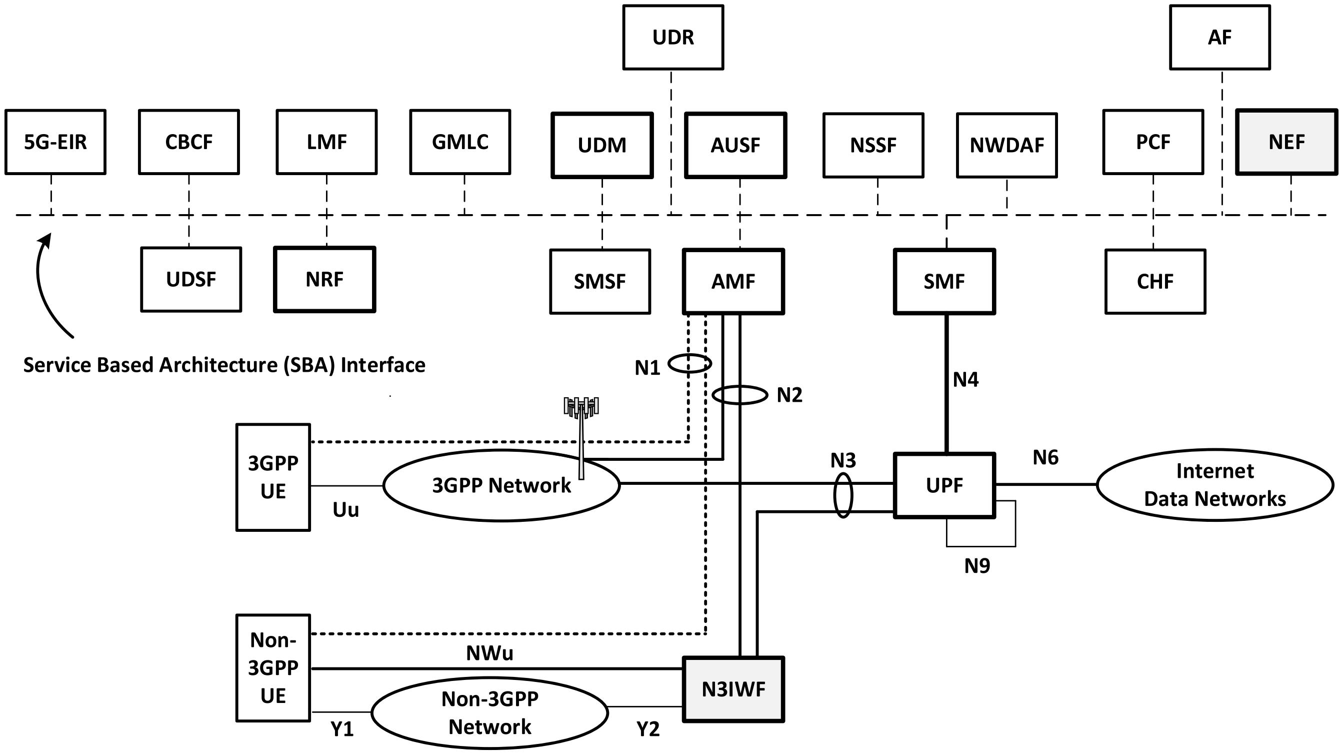

Fig. 4. 5G Core cloud-native architecture abstracted and context of supporting both 3GPP and Non-3GPP access networks.

TABLE II
ATSC 3.0 OFDM NUMEROLOGY EXTENDED FOR MOBILE

Freq MHz	BW MHz	[N]	Fs MHz	IFFT	T_u µs	CP µs	CP Fraction	ISD Km	ΔF Hz	Doppler Km/Hr
200	5-10	32	12.288	4096	333	33	10%	10	3000	1690
200	5-10	32	12.288	8192	667	100	15%	30	1500	845
200	5-10	32	12.288	16384	1333	200	15%	60	750	422
200	5-10	32	12.228	16384	1333	333	25%	100	750	422
500	5-10	32	12.288	4096	333	33	10%	10	3000	675
500	5-10	32	12.288	8192	667	100	15%	30	1500	338
500	5-10	32	12.288	16384	1333	200	15%	60	750	168
500	5-10	32	12.288	16384	1333	333	25%	100	750	168
600	5-10	32	12.288	4096	333	33	10%	10	3000	562
600	5-10	32	12.288	8192	667	100	15%	30	1500	280
600	5-20	54	20.768	16384	790	200	25%	60	1266	238
600	5-15	40	15.36	16384	1067	264	25%	80	938	176
700	5-10	32	12.288	4096	333	33	10%	10	3000	481
700	5-10	32	12.288	8192	667	100	15%	30	1500	240
700	5-20	54	20.768	16384	790	200	25%	60	1266	204
700	5-15	40	15.36	16384	1067	264	25%	80	938	150

discussed in Section VII. In last two columns is ΔF (Hz) and mobile doppler performance km/Hr. Note: new ΔF (Hz) values and the new 4096 IFFT size as compared to Table I that are optimized for fixed television service, but now extended for mobile. It should be appreciated with 7 bits in L1 signaling the value [N] (3) this is only one example of the extensibility available.

V. 5G CORE INTRO CONTEXT 3GPP AND NON-3GPP ACCESS

Figure 4 is the new 5GC with a cloud-native Service Based Architecture (SBA) [14] and with several relevant functions discussed. The paradigm shift brought by the 5GC compared to legacy 3GPP standards is the method used for separation of control and user plane in the core network shown in Figure 4. The control plane entities are instantiated as software functions shown running in the cloud environment using methods of large IT players by using a SBA. The dashed lines are interfaces connecting all control plane functions.

The 5GC architecture is in great contrast to the past standards such as GSM, WCDMA and LTE which each had different core networks, radio access networks and used different protocols, etc. This monolithic nature ends with 5GC designed to be abstracted (non-aware) of access network, 3GPP or Non-3GPP.

The control plane functions are no longer static in their function. Instead, each of the functions shown in Figure 4 must first register with Network Repository Function (NRF) entity shown using interface and APIs defined. Then, once each control function's services are registered in NRF, they become available to the other registered functions by discovery via the NRF. This flexibility allows dynamically chaining together functions to build end-to-end services and this is termed 5G network slicing and uses the methodology of large cloud players such as Facebook, Amazon, Netflix, Google, etc.

This was a deliberate decision by 3GPP to increase flexibility of 5G system, to be innovative and to remain competitive using methodology of large cloud players. This allows the 5G NR data capacity to be translated into increased revenues, competitive services and enable new 5G industry verticals.

The 5GC user data plane (U) runs from the Internet or data network via N6 interface to the User Plane Function (UPF) shown and then via N3 interface to 3GGP radio access network and using N3 to Non-3GPP radio access network using Non-3GGP Interworking Function (N3IWF) shown.

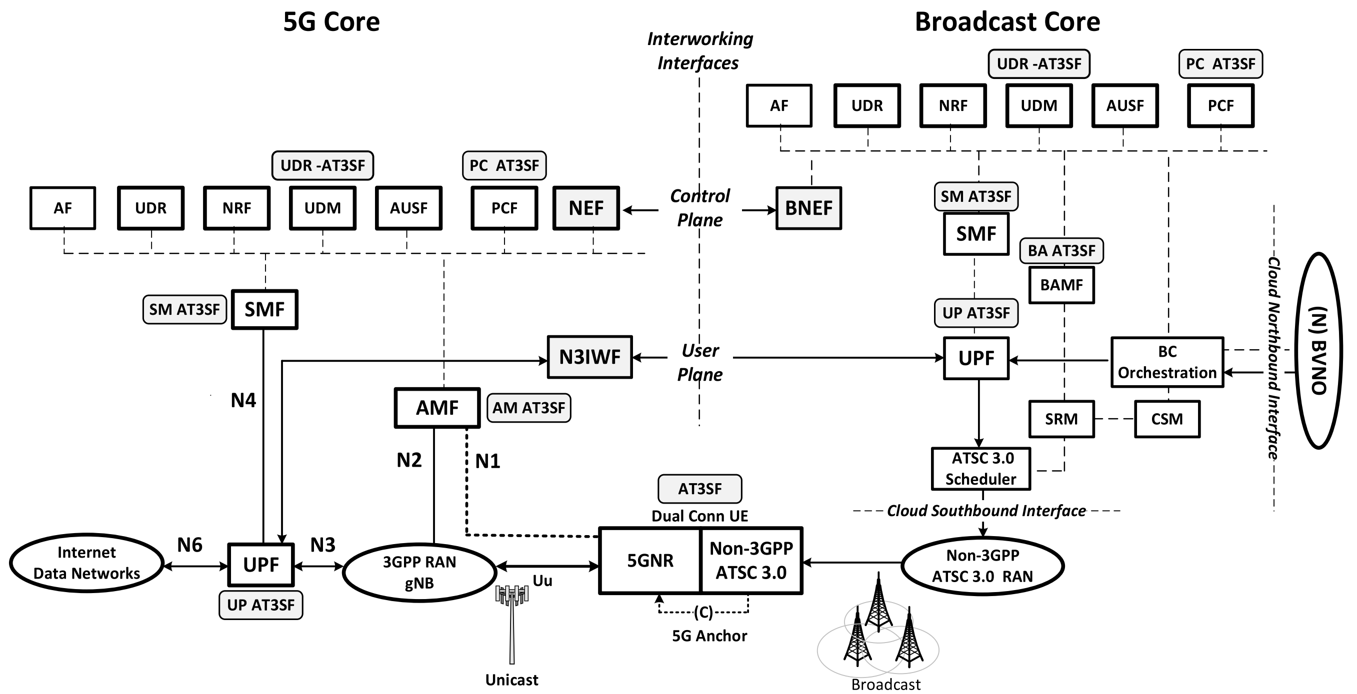

Fig. 5. The 5G Core Interworking with the Broadcast Core in a Next Gen Wireless Platform (NGWP).

The Access Mobility Function (AMF) interacts with the 3GPP radio access network and N3IWF using N2 interface and the UE via N1 interface respectively. The Session Management Function (SMF) via N4 to UPF manages all sessions and allocation of IP addresses, etc. The Authentication Server Function (AUSF) authenticates the UE. The Unified Data Management function (UDM) stores subscription data and generates authentication data for AUSF. The Unified Data Repository (UDR) is a generic database enabling stateless operation of all functions in cloud for flexibility and resiliency to support interworking with other core networks and external entities, the 3GPP has defined the Network Exposure Function (NEF). This gives access or controlled exposure of 5GC network core functions to external entities and is also used in 5G vertical use cases, and broadcast 5G convergence Section VII.

VI. 5G Core Broadcast Core Interworking

Figure 5 introduces high-level view 5GC interworking with a shared Broadcast Core (BC) to prepare for discussing the proposed broadcast 5G convergence architecture in Section VII. The BC in Section VII is an integrated part of a Next Gen Wireless Platform (NGWP), which is a multi-tenant system platform shared by licensed broadcasters to converge broadcast services with 5G MNO using Release 16 methodology.

The convergence is coordinated both at IP layer interworking (5GC and BC) and with aligned 5G NR and ATSC 3.0 RAT schedulers and with ATSSS rules in core networks and at the dual connected UE shown. The 5GC is used as anchor for UL ATSC 3.0 broadcast which has only DL and (U) as first shown in Figure 2.

The BC shown in Figure 5 is a cloud-native architecture and uses some of the control plane functions discussed in Figure 4 for the 5GC. The BC is shown to the right of interworking interfaces for the control and user planes shown. Several blocks, such as BC orchestration, spectrum pools, Broadcast Virtual Network Operator (BVNO) and the cloud interfaces shown are a part of the NGWP discussed in Section VII.

The interworking and ATSSS functions (AT3SF) are shown as greyed blocks and their functionality will be briefly discussed. The 5GC control plane interworking entity is the NEF as was discussed and defined in [2]. The BC control plane interworking entity is the Broadcast Network Exposure Function (BNEF). The 5GC user plane interworking entity is the N3IWF, and the BC user plane interworking entity is the UPF as shown.

For normal (non-interworking) operation, the 5G NR user plane IP data flow is from the Internet or data network via N6 to UPF then via N3 to the gNB in 3GPP RAN. The normal (non-interworking) operation for broadcast is from BVNO to broadcast UPF and then ATSC 3.0 scheduler and then ATSC 3.0 exciter in Non-3GPP broadcast RAN as shown in Figure 5.

The interworking between 5GC and BC provides the bi-directional IP flows to support the converged use of unicast and broadcast at IP layer in core networks and at the dual connected UE using ATSSS Release 16.

The 3GPP ATSSS Release 16 describes the access traffic steering, switching or splitting by using these definitions [16].

Steering is the procedure that selects an access network for a new data flow and transfers all traffic of this data flow over the selected 3GPP or non-3GPP access network.

Switching is the procedure that moves all traffic of an ongoing data flow from one access network to another access network in a way that maintains continuity of the data flow using 3GPP and non-3GPP access networks.

Splitting is the procedure that splits data flow across access networks. With some traffic of data flow transferred via 3GPP and other via a Non-3GPP access network simultaneously.

In this paper, the ATSSS functionality is used and discussed in the context of the proposed broadcast 5G convergence architecture. Currently, in 3GPP ATSSS, the non-3GPP access network can be Wi-Fi 6 [23], fixed access network [17], satellite [18] or as here proposed, ATSC 3.0 broadcast.

The ATSSS functionality is determined by the core network policy established on PCF, PC-AT3SF, and by the ATSSS rules distributed as shown to the user plane and control plane AT3SF functions in 5GC and BC. The ATSSS rules are then distributed to dual connected UE. The ATSSS switching functionality can be supported using MPTCP protocol [26] above IP layer or ATSSS-LL at lower layer on the UPF shown in BC for broadcast multicast IP flows.

When the dual connected UE shown in Figure 5 attaches to the 5GC, the UE announces to the 5GC its capabilities including a broadcast Non-3GPP RAT (ATSC 3.0) under ATSSS. Then with ATSSS policy and rules distributed in the 5GC, BC, and UE. The network conditions such as congestion 5GC or the signal conditions at UE are used by ATSSS to improve network efficiency and QoS for users in an agnostic way. The 5GC and BC typically interwork under a Service Level Agreement (SLA), between broadcaster (BVNO) and MNO, and will be discussed in Section VII.

The interworking provides for managed bi-directional IP flows for the explicit converged use of unicast and/or broadcast services at the dual connected UE with ATSSS Release 16. In Figure 5 the IP data flow in 5GC can be directed under ATSSS from UPF in 5GC to N3IWF to UPF in BC to the ATSC 3.0 scheduler to the Non-3GPP broadcast RAN and finally the broadcast signal is received at dual connected UE. Conversely, in the BC the IP data flows can be directed from UPF in BC to N3IWF and then to UPF in 5GC then via N3 to 3GPP RAN and gNB, and finally unicast signals are received at dual connected UE using ATSSS rules and decisions made in core networks and dual connected UE based on real-time conditions.

In 3GPP ATSSS Release 16, the user plane switching functionality is supported in 5GC and BC using the UPF and at the dual connected UE. The MPTCP protocol can be used for TCP/IP flows and the ATSSS-LL (Lower Layer) can be used for any IP flow including UDP, TCP, etc.

Both ATSSS switching methods MPTCP and ATSSS-LL can be used simultaneously and selected on an IP flow basis on UPF and at the dual connected UE. Then, when dual connected UE attaches to the 5GC, it announces its capabilities and selections under ATSSS rules established. For ATSC 3.0 broadcast the ATSSS-LL method is used only in BC on UPF and at UE with middle-layer IP stack support for UDP/IP multicast IP flows [2].

VII. Proposed Shared Broadcast Core and NGWP

Effective March 5, 2018, the FCC adopted portions of the ATSC 3.0 broadcast standard (A/321, A/322) and permited its use on a voluntary, market-driven basis in the United States [16]. These FCC rules permit broadcasters voluntarily deploying ATSC 3.0 to enter private business agreements to share their 6 MHz broadcast channel and use a common transmission infrastructure to innovate using the ATSC 3.0 standard. However, the constraint is the ATSC 3.0 standard lacks both a method and system architecture for the efficient sharing of broadcast spectrum and transmission infrastructure.

The NGWP architecture is shown in Figure 6 that enables broadcasters in the U.S. to share spectrum efficiently using a virtualized Radio Access Network vRAN infrastructure to innovate using ATSC 3.0. Also, each broadcasters can have the option to explore new broadcast 5G converged services and mobile business models using the extended OFDM numerology discussed in Table II. The NGWP is a SDN/NFV cloud native multitenant platform environment optimized to enable the broadcast spectrum to be shared for ATSC 3.0 services. The NGWP includes integrated BC that provides the for efficient automated spectrum sharing and the use of a common broadcast RAN infrastructure.

The NGWP virtualizes the broadcast spectrum as agreed by the broadcasters through private sharing agreements and this is reflected in Broadcast Market Exchange (BMX) policy running in NGWP. The shared spectum resources usage is accounted for by the establishment and management of a spectrum resource pool for each ATSC 3.0 6 MHz channel being shared in NGWP.

A broadcaster using the services of NGWP in this paper is termed a Broadcast Virtual Network Operator (BVNO). A BVNO is shown at top of Figure 6 sending IP flows from an external automation playout environment into NGWP using the northbound interface. The BVNO is authorized and authenticated by the BMX orchestration entity which has the policy running reflecting the specfics of the spectrum sharing agreements of all BVNO.

The NGWP has edge datacenters shown each with a Spectrum Resource Manage (SRM) entity that controls (N) ATSC 3.0 schedulers to build (N) 6 MHz ATSC 3.0 frames instructed by BMX orchestration entity under multi-tenant sharing. The ATSC 3.0 scheduler creates digital baseband frames that are sent via NGWP southbound interface to the ATSC 3.0 exciter in the shared RAN environment, which converts digital baseband to an analog RF signal for broadcast into spectrum. This supports the several coherent transmitters of a single frequency network for benefit of transmitter spatial diversity discussed Section III. The signal is then shown being received by a commercially available ATSC 3.0 receiver for fixed services selected by the BVNO.

The SRM entity creates a broadcast frame record for each frame and this is used to validate each tenants usage of spectrum resources in real-time based on BMX policy for the licensed local geographic area served from edge datacenter. This could also form a national platform using the Cognitive Spectrum Management (CSM) entity shown in Figure 6 having a consolidated global view of all regional edge datacenters. The CSM abstracts the details of spectrum pools from and provides service to the BMX orchestration entity shown. The BMX orchestration entity has the business view, policy, charging, etc. to monetize spectrum resources in all pools.

The term Broadcast Market Exchange BMX relates to the option of treating the BVNO spectrum resources as commodities in a market exchange. Then each BVNO has the option to

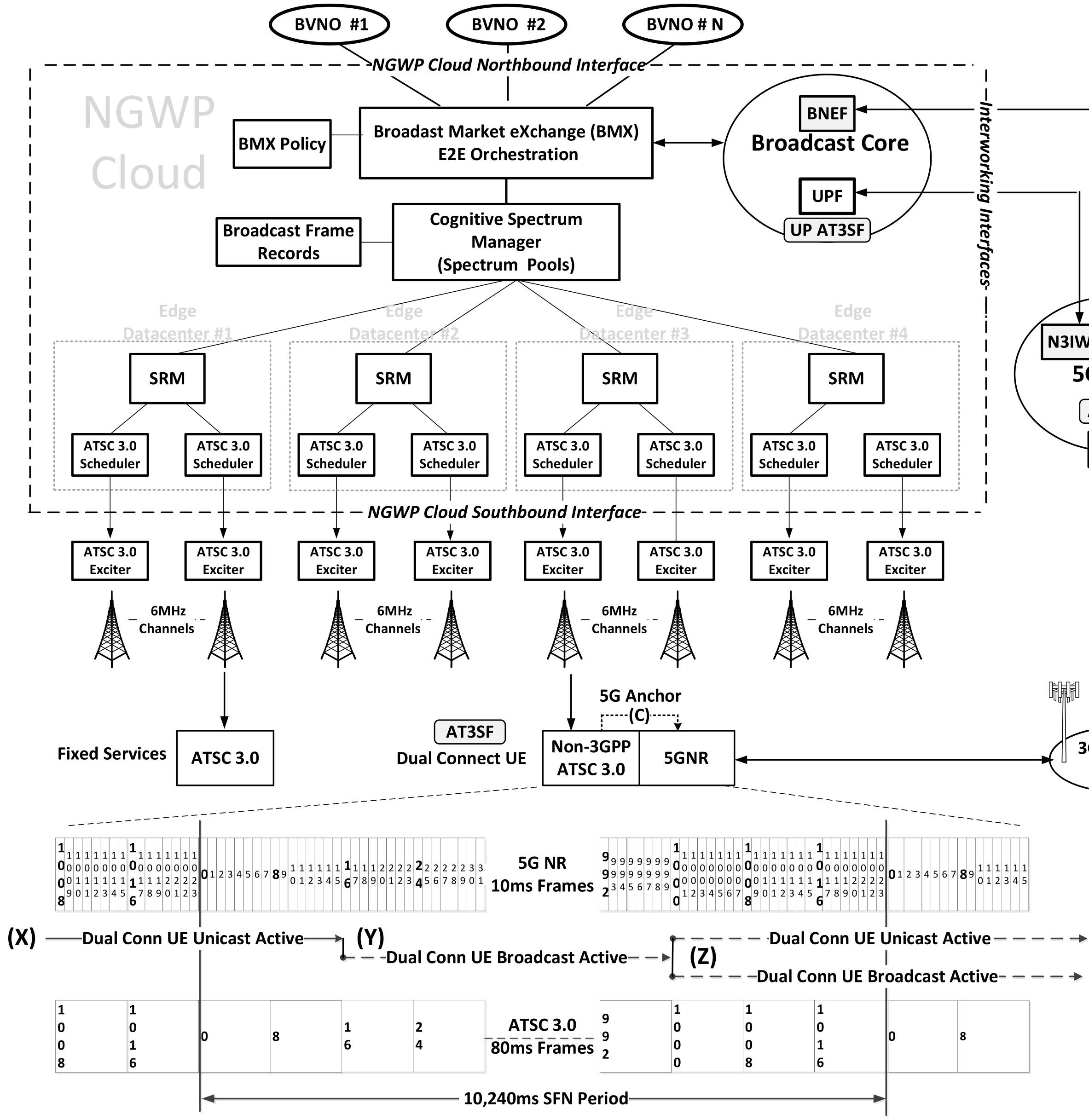

Fig. 6. Converged 3GPP 5G NR and Non-3GPP ATSC 3.0 Services in 5GC / BC and at Dual Connected UE ATSSS release 16.

dynamically sell or buy additional spectrum resources using a BMX with other participating tenants. This automation sets the stage to put broadcast spectrum into play for innovative mobile broadcast 5G convergence business models with a 5G MNO as another tenant interworking under SLA in the future.

The 5GC and BC interworking entities previsiouly discussed in Figure 5 are now shown in Figure 6 with IP data flows ATSSS switched in the UPF entities connecting either the 3GPP or Non-3GPP RAN.

The attention is now turned to the timeline shown at the bottom of Figure 6 of the time aligned frames with synchronized system frame number counts locked to TAI, shown from perspective of the dual connected UE. The timeline at points (X), (Y), (Z) shows the result of the coordinated unicast and broadcast RAT schedulers under ATSSS Release 16 which can be simultaneously active on UE.

Then, using ATSSS policy, rules and conditions in the core networks and with reports from the UE via Performance Measurement Function (PMF) (not shown) determines the ATSSS functionality to improve network efficiency and quality of service to consumer in an agnostic way. Using AT3SF, the UPF is instructed, and by using interworking interface, can steer or switch IP traffic flows to the selected RAN. Also, ATSSS splitting enables same IP flow to be split to both 3GPP and Non-3GPP RANs and received by dual connected UE shown.

As shown at SFN count instant (X) is an example of IP flow for a service using only the unicast RAT. Then at SFN count instant 0016 (Y) the IP data flow for the service is switched with only the broadcast RAT active. Then, continuing in time to SFN count at instant 1000 (Z) the service IP data flow is split with both unicast and broadcast RAT active ATSSS Release 16.

Other 5G use cases (not shown) using SFN count established in the core network and at UE can also be applied to broadcast. This can be used to enable Disconnected Reception (DRX) on the UE, were the UE sleeps (quiescent state) and awakes and becomes active at known SFN count instant to receive, which saves battery on the UE. Also, as in 5G IoT use cases, a device becomes active to receive a burst of data on a known SFN count cadence signaled by network to increase IoT device battery life.

Moreover, by using the frame alignment and synchronized SFN count in L1 signaling proposed, in both core networks and at the UE. The UE upper layers are then abstacted from which channel unicast or broadcast used for IP flow for a service under ATSSS. This novel architecture for broadcast 5G convegence proposed is a useful contribution for broadcast and low-band spectrum in 5G for future research and consideration.

Another synergy of NGWP is support for broadcast network slicing, analogous to 5G network slicing [20]. The automation of broadcast slice lifecycle is managed using the framework of Linux foundation Open Network Automation Platform (ONAP) project to align broadcast [15].

VIII. Conclusion and Future Research

This paper introduced a novel method for broadcast 5G converged services, aligned using methodology available in Release 16. The proposed method shown was of a 5G MNO with 5GC and BVNO using services of NGWP and with 5GC and BC interworking using un-trusted non-3GPP ATSC 3.0 RAT with dual connected UE using 3GPP Release 16.

Moreover, in USA a new 5G MNO has emerged in market and has started to build out a new nation-wide greenfield 3GPP Release 16 5G system architecture. The goal is to provide efficient utilization of low-band, non-contiguous broadcast spectrum using innovative broadcast 5G heterogeneous networks and new business models.

Some of our future research is aimed at understanding the potential use cases and value of time aligned frames with synchronized L1 signaling and cooperating 5G and ATSC 3.0 schedulers in context of ATSSS. Other areas of interest include use of artificial intelligence AI [19] and the Linux Foundation's Open Network Automation Platform (ONAP). The importance of security and interworking is recognized by authors but was not discussed and is another central focus of future research.

Finally, broadcast, Wi-Fi 6 and 5G convergence is being studied using similar methodology and a future industry collaborative whitepaper on this subject is being planned.

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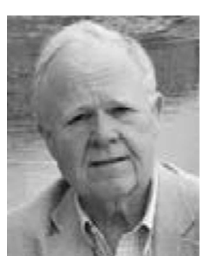

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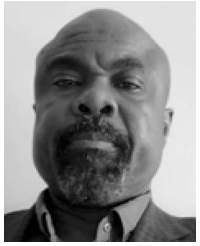

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