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Technical Papers

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From the Editors

Welcome to Volume 6 Issue 1 of the *Journal of Network Operations*, a publication of collected papers by the Society of Cable Telecommunications Engineers (SCTE) and its global arm, the International Society of Broadband Experts (ISBE).

Cable operators have been using receive modulation error ratio (RxMER, sometimes called "SNR") for years to characterize the health of digital signals carried on their networks. Test equipment manufacturers have supported RxMER measurements in their field instruments for nearly as long as digital has been part of our vernacular, but care must be taken when making those measurements. Brad Niems, Director of Business Development for Amphenol Broadband Solutions, provides in his letter to the editor a recommendation to help prevent test equipment overload, especially at the output of nodes and amplifiers where a significant amount of tilt exists: insert a bandpass filter in the signal path. That bandpass filter reduces the total power present at the test equipment input, allowing more reliable RxMER measurements to be performed.

Service providers are rolling out 5G (fifth generation mobile telecommunications technology) worldwide, which uses a variety of frequencies: frequency range 1 (FR1, below 7.125 GHz) and frequency range 2 (FR2, starting at 24.25 GHz). 5G technology can use both licensed and unlicensed spectrum. In the paper "5G New Radio Unlicensed (NR-U): An overview," Charter's Amitav Mukherjee, Reza Hedayat, Frank Azcuy, and Maulik Vaidya discuss use cases for 5G operation on unlicensed frequencies, and how 5G can coexist on those frequencies with other services such as Wi-Fi. Indeed, the authors emphasize how and why "the two technologies…are not sworn mortal enemies."

A relatively new tool in the cable network architecture toolbox is what is known as distributed CCAP architecture (DCA), which includes remote PHY and remote MACPHY – the latter also called flexible MAC architecture. R-PHY, for instance, relocates the physical layer electronics to a remote PHY device (RPD) in a shelf or node, while the MAC electronics stay in the headend or hub. DCA has many benefits, but along with those benefits comes the need for creation of new ways of doing inventory management (shelves, nodes, RPDs, and more), data collection, alerting, and troubleshooting. Comcast's Mehul Patel, Nathan Buffington, and David Marquis discuss evolving access network telemetry from pull-based to push-based real-time streaming data in their paper "R-PHY DCA Telemetry Data Management." Included in their discussion are a look at the benefits of push-based telemetry data; benefits and challenges associated with creating visualization dashboards for operational use; use cases for tools that take advantage of push-based telemetry data; and some of the disadvantages they dealt with when conforming the data to support legacy and point-in-time tools for monitoring and alerting.

The cable industry has for much of its existence catered primarily to the residential market. Operators can and are serving the business sector, too, including enterprises within and near their service areas. Bell Labs Consulting's Ronald Hasenberger, Ashish Kumar, Astha Sharma, and Vassilka Kirova, in their paper "Designing Operating Models for Serving Enterprise Markets," present and examine several business models that allow cable operators to participate with third parties and enterprises in different value clusters across various industry verticals, focusing on synergies with the cable operator's current business models. The paper includes a closer look at four business models: bit pipe provider, infrastructure provider, platform provider, and solution provider. Those business models can serve as a set of blueprints that can be used as foundation for designing operating models for the emerging diverse needs of enterprises.

We are grateful for the individuals who contributed to the *Journal of Network Operations*, including the authors, reviewers, and the SCTE·ISBE publications and marketing staff. We hope you enjoy this issue of the *Journal*, and that the selected papers provide inspiration for new ideas and innovations in cable network operation. If you have feedback on this issue, have a new idea, or would like to share a success story please let us know at journals@scte.org.

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Testing RxMER at the output of nodes and amplifiers

Letter to the Editor prepared for SCTE•ISBE by

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Over the years it has been accepted that there must be transmit equalization (slope) compensation at the output of all analog nodes and distribution amplifiers. This is to counter the roll-off of both the hardline coaxial cable and the roll-off created by the insertion of multiple hardline taps and other passives in line with the coax cable run. It is further understood that the vast majority of nodes were originally designed for a maximum upper frequency limit ranging from 550 MHz to 750 MHz or higher. The end result of these designs is that the span between the node and the first amplifier, or between amplifiers, represents a length that was reasonably engineered in many cases for a 750 MHz bandwidth.

With the creation of DOCSIS 3.1, FDX and the upcoming DOCSIS 4.0, a new upper frequency limit of up to 1218 MHz (ultimately growing to 1794 MHz) that all DOCSIS 3.1 devices (I-CMTS or I-CCAP, R-PHY or R-MACPHY) operate to, and also realizing that the coaxial network is at a fixed length from previous design decisions, it is clear to all that up to 22 dB of positive slope (tilt) must be transmitted from either the traditional analog node or from the R-PHY or R-MACPHY (digital node) in order to satisfy the higher frequency losses due to the extended bandwidth.

The main point here is not to criticize older design decisions, but rather to point out the reality that the output from 100 MHz to 1218 MHz will more than likely need up to 22 dB of slope (tilt). The 22 dB slope presents the very real and difficult task of measuring the node or amplifier output for receive modulation error ratio (RxMER) performance accurately.

The CATV analyzer that the RF technician has been given for measurements in the field and, more importantly, that is also used for establishing performance objectives, likely will have serious dynamic range limitations.

By way of example, for measuring DOCSIS 3.1 accurately, it is important to understand that the RF power being measured has grown from DOCSIS 3.0 that is used today everywhere in the world and the analyzers have not adapted in kind. The situation is confirmed by the fact that the RF technician is armed with a CATV analyzer that is barely capable of measuring equalized RxMER = 47 dB.

For purposes of this scenario, assume that the system in question is a 1005 MHz EURO-DOCSIS 3.0 R-PHY or D-CCAP device installed in the CATV plant, replacing the analog node that was there previously. Further assume the use of a field meter capable of measuring up to about 47 dB RxMER on a flat spectrum from 100 MHz to 1 GHz.

So, now the reality. Standard practices result in the D-CCAP or R-PHY having to transmit approximately 65 dBmV total power, with a positive slope of 18 dB, to ensure that the signal reaches the input to the next amplifier in cascade with acceptable levels and tilt. The output positive slope requirement holds true for an N+0 as well, in order to provide a reasonable tilt and level for either the set-top box (STB) or DOCSIS cable modem at the end-of-line to operate in a satisfactory manner.

Figure 1 reflects these standard practices as produced by the R-PHY or D-CCAP (R-MACPHY) node.

The end result is that one ends up attempting to measure the following transmit spectrum at the output of the node.

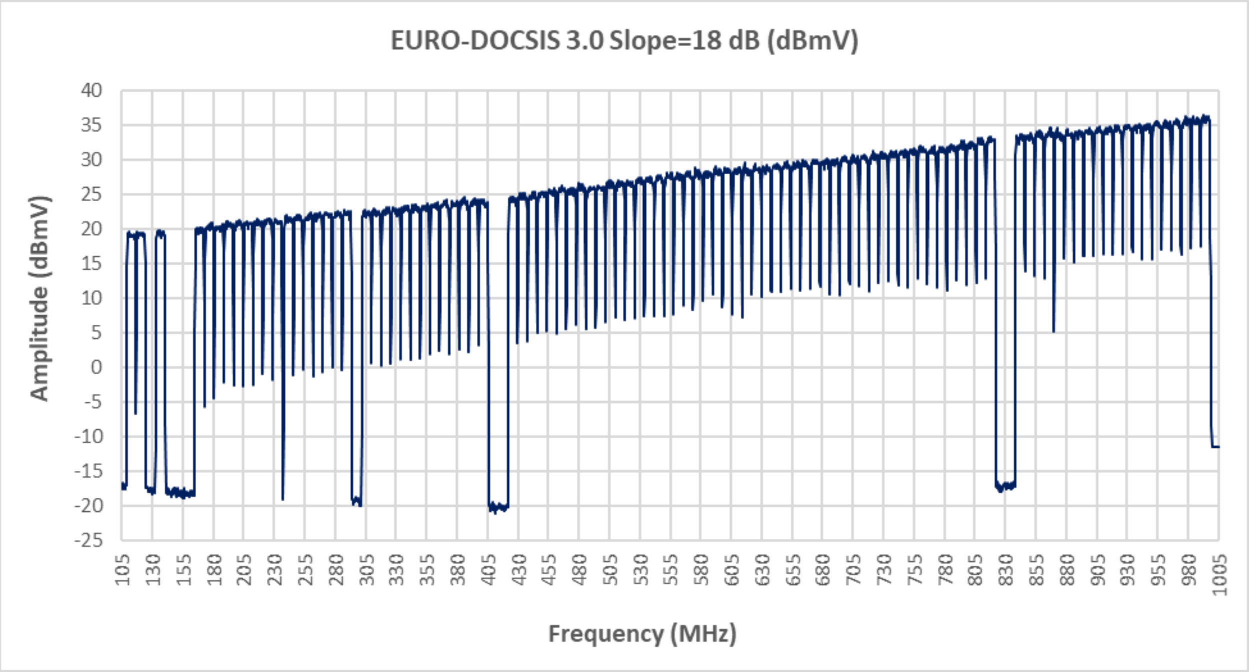

Figure 1 - R-PHY or R-MACPHY (Digital Node) - Typical Output Spectrum

Total Power (105 MHz to 1005 MHz) = **64.5 dBmV**

Required RxMER per carrier = 43 dB

Power - (105 – 300) MHz = 48.1 dBmV

Power - (300 – 500) MHz = 52.2 dBmV

Power – (500 - 1005) MHz = 64.1 dBmV

To further complicate the matter, the RF technician is instructed to verify the RxMER in the 300 MHz to 500 MHz region which means the CATV analyzer is being used to assess RxMER in the presence of the entire transmitted spectrum.

One can clearly see that the power from 500 MHz to 1005 MHz contains most of the total power while the RF technician must attempt to estimate or measure the RxMER in the 300 MHz to 500 MHz region which is several dB lower than the total power, and in particular the power above 500 MHz

Given that there is roughly 18 dB of slope or tilt in the node's output spectrum the RF technician must perform one of the following adjustments:

- Adjustment Option 1 – Lower the sensitivity on the CATV analyzer by adding attenuation so the instrument is not driven non-linearly by the higher-powered spectrum above 500 MHz. This would work, but by increasing attenuation, the signal being measured would be lowered to a level where it is degraded by the noise floor of the analyzer. The end result is one gets a stable RxMER estimate; however, the RxMER estimate does not reflect the node's RxMER output capability at all. Instead, the RxMER being reported is the direct result of the CATV analyzer noise floor now being part of the measurement. Therefore, the measurement is not accurate.

- Adjustment Option 2 – Playing with the attenuation (decreasing it somewhat from the adjustment in Option 1). Ironically this option is a veiled attempt at trying to determine how much of the Option 1 safe measurement approach was merely reflecting the CATV analyzer limitations and not the actual RxMER of the node. The irony is the RF technician will usually be instructed to push the linearity limits a little to see how much the RxMER estimate can improve. If the instrument has an overload light and it is only flashing a little rather than constantly on, the CATV analyzer is going to report the best RxMER possible. Of course, the uncorrectable codeword errors may actually increase during this measurement procedure. As with Adjustment Option 1, the measurements are not accurate.

So now the RF technician has what they feel is the best RxMER estimate possible given the circumstances since they cannot get a true accurate measurement. Let's say for sake of argument that the estimate was 41.5 dB. So, as is the case now, the RF technician doesn't know whether to report the RxMER estimate as a failure or assume it is good enough and move on to the next node or amplifier.

What has just been described goes on every single day in the field and is widely known throughout our industry. In fact, some have even come up with calibration estimates on how to determine what the real RxMER measurement should be!

In reality, however, there is no need to have to go through this procedure of overdriving the front end of the test equipment and playing with the input attenuation in an effort to see if the CATV analyzer can report a 43 dB or higher RxMER.

This is why the author and his colleagues spent considerable time working closely with industry experts such as Jack Moran and others to define a better, more accurate, approach. The fundamental concept is to simply connect a bandpass filter in series with the analyzer. This will accomplish the important function of significantly limiting the total power to the CATV analyzer input.

With this in mind, let's revisit the scenario displayed in Figure 1 but examine what the same CATV analyzer experiences when a 400 MHz bandpass filter (center frequency) with an approximately 200 MHz-wide passband is connected in series with the CATV analyzer.

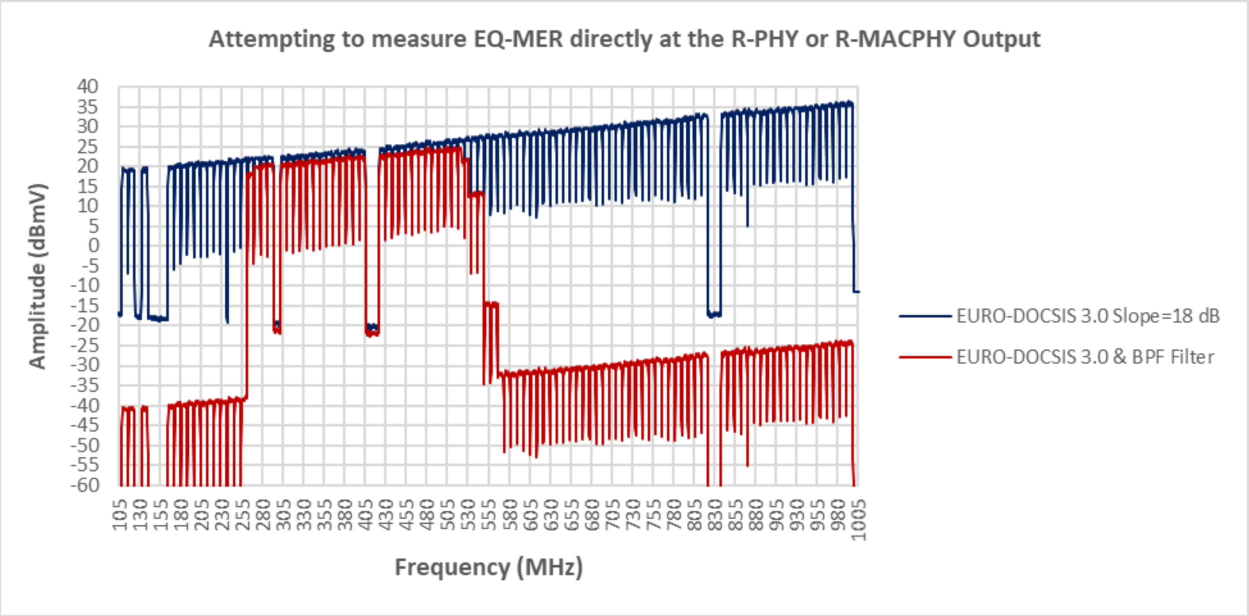

Figure 2 - CATV analyzer connected to R-PHY or R-MACPHY node output via a bandpass filter

Examining Figure 2, one can observe the following:

- The CATV analyzer only sees the energy in depicted in red and the total power = 51.7 dBmV. This value is a very long way from the total power of 64.5 dBmV that would be seen without the filter.
- Besides the obvious reduction in total power, all the higher signal power that required attenuation to be added no longer exists.
- It can also be observed that the filter itself does not eliminate the slope in the filter passband
- Finally, the original signal power in the approximately 300 MHz to 500MHz bandwidth is lowered by 1.8 dB, which is the passive filter insertion loss, so the only calibration required for accurate RX level recording is to add 1.8 dB to the level.

In summary, with the use of the bandpass filter and with very little attenuation being needed to perform the RxMER estimates, one would expect to easily report the RxMER estimate at the limits of the CATV analyzer (say 45 dB to 47 dB) rather than the 37 dB to 39 dB that Jack Moran had indicated he had to deal with in the field. This was tested in the field with a bandpass filter in series with a laboratory grade instrument (Keysight UXA Series N9040B) to measure a node’s output RxMER. The results ranged between 48 dB and 50 dB as opposed to the 37 dB to 39 dB that had been reported using the cable operator’ss CATV analyzer without a bandpass filter. The CATV analyzer also reported higher RxMER with the bandpass filter than without.

The bottom line is that a suitable bandpass filter kit should be used in conjunction with test equipment – whether laboratory grade or the more common field-grade meters used by technicians – when measuring RxMER performance at the output of nodes and amplifiers.

5G New Radio Unlicensed (NR-U): An overview

The interplay between Wi-Fi and cellular technologies

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

Fifth-generation (5G) cellular technology, known as New Radio (NR), is being deployed rapidly by mobile network operators across the globe. While cellular networks traditionally operate in licensed radio spectrum, NR has also been enhanced for unlicensed spectrum operation as a part of the Third Generation Partnership Project (3GPP) Release 16 cycle [1]. In this paper, the authors provide a glimpse into how 3GPP and IEEE 802.11 technologies can employ unlicensed spectrum to satisfy a variety of use cases whilst sharing the spectrum politely with one another. Section 2 offers a perspective of such co-existence from a radio technology perspective. Section 3 provides an overview of how integration of these two technologies is envisioned to occur at a higher-than-radio-level. Section 4 hints at how and when to use 3GPP or IEEE technologies for different use cases.

2. Spectrum sharing between NR-U and Wi-Fi

NR Unlicensed (NR-U) was designed to share the spectrum with IEEE 802.11ac and IEEE 802.11ax (collectively referred to as `Wi-Fi’). In this section we provide an overview of the key design features and challenges associated with fair coexistence between these disparate radio access technologies. We do so by looking at the various layers – (physical layer (PHY), upper layers (radio layers above PHY), and radio frequency (RF) layer – of NR-U which play a crucial role in the overall fair co-existence mechanisms.

2.1. What was NR-U designed to address?

NR-U has been designed for operation in the 5.150 GHz to 7.125 GHz[1] unlicensed spectrum. It is a complement to existing unlicensed technologies and is intended to opportunistically improve data connectivity for the use cases and applications that 5G NR is expected to offer.

The following deployment scenarios are supported in 3GPP NR Release 16 [2], and are depicted in Figure 1:

- Scenario A: Carrier aggregation between licensed band NR (PCell[2]) and NR-U (SCell[3]).
    - NR-U SCell may have both downlink (DL) and uplink (UL), or DL-only.
- Scenario B: Dual connectivity between licensed band LTE (PCell) and NR-U (PSCell[4]).
- Scenario C: Stand-alone NR-U that is purely based on unlicensed spectrum.
- Scenario D: A stand-alone NR cell in unlicensed band and UL in licensed band.
- Scenario E: Dual connectivity between licensed band NR and NR-U.

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[1] Different regions of the world have different gaps in this spectrum range. The gaps correspond to spectrum utilization by different technologies (e.g., the USA uses, at the time this document was written, 5.925 GHz to 5.975 GHz for DSRC (see [7]).

[2] PCell refers to Primary Cell, see [5].

[3] SCell refers to Secondary Cell, see [5].

[4] PSCell refers to SpCell of a secondary cell group, see [6].

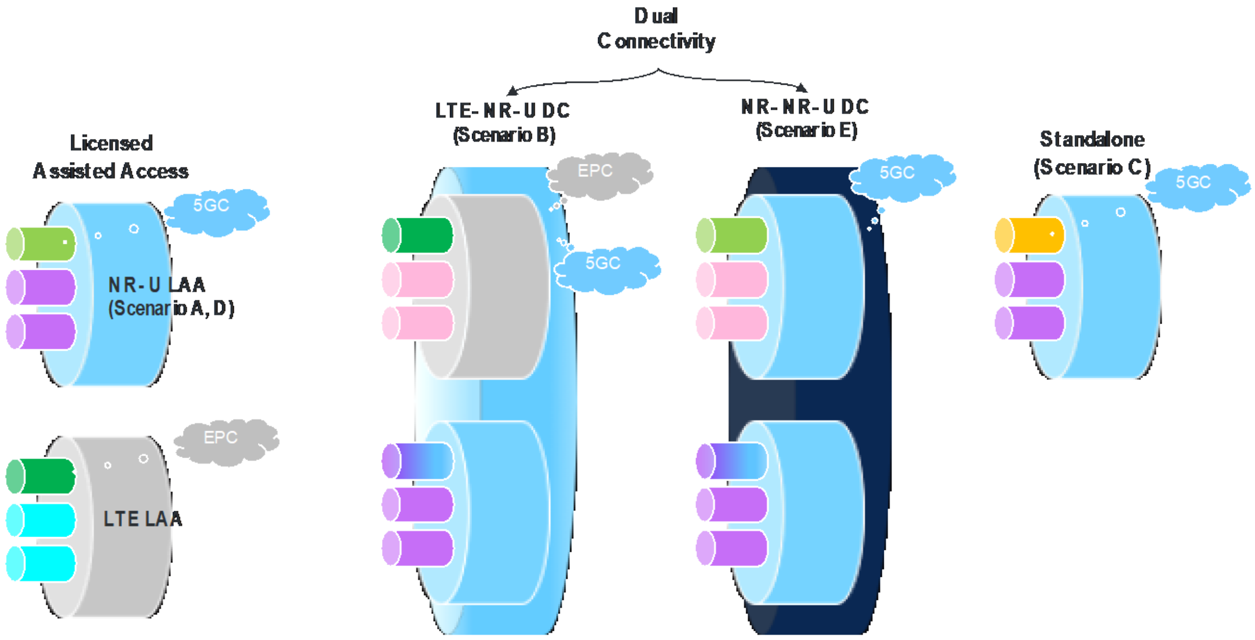

Figure 1 - NR-U scenarios supported in 3GPP Rel-16.

As just discussed, there is considerable flexibility available in terms of deploying NR-U. The availability of stand-alone NR-U is a key distinguishing factor from fourth-generation (4G) unlicensed cellular technologies such as long term evolution (LTE) with licensed-assisted access (LAA), which requires a licensed band anchor. Conversely, the stand-alone feature complicates the system design since all NR operations and procedures (for example, paging and handover) must now be made sufficiently robust for unlicensed bands where channel access is not guaranteed.

For comparison with NR-U, the following presents a few aspects of 802.11ac and 802.11ax standards:

- Uses cases: 802.11ax has similar use cases as the previous 802.11 generations, e.g., 11n and 11ac, but with emphasis on environments such as wireless corporate offices, outdoor hotspots, dense residential apartments, and stadiums.
- Performance: In previous generations, including 802.11ac, the focus has been on improving aggregate throughput by increasing bandwidth, adding MIMO spatial streams, and/or using larger modulation constellations. However, 802.11ax additionally focused on improving metrics that reflect user experience, such as average per-station throughput, and area throughput.
- Technologies: 802.11ac is defined for operation in the 5 GHz band, while 802.11ax is defined for operation in the traditional 2.4 GHz band as well as 5 GHz and 6 GHz bands (5.150 GHz to 7.125 GHz). Both 11ac and 11ax support wide channel bandwidth up to 80 MHz and 160 MHz (as well as non-contiguous 80+80 MHz). 802.11ac and 11ax support up to 256-QAM and 1024-QAM respectively. While 11ac uses orthogonal frequency division multiplexing (OFDM) as prior generations, 11ax is the first generation to use orthogonal frequency division multiple access (OFDMA) for improved multi-user multiplexing. Also, 11ax introduced new techniques to enhance power saving, such as target wakeup time (TWT), as well as techniques to enhance spatial reuse by adjusting channel access thresholds.

2.2. Coexistence Framework

NR-U has been designed as a single global solution despite different worldwide (or part thereof) regulations in the 5.150 GHz to 7.125 GHz spectrum. The channel access framework is based on a listen-before-talk (LBT) mechanism that utilizes energy detection (ED). NR-U LBT closely mirrors the carrier-sense multiple access/collision avoidance (CSMA/CA) and enhanced distributed channel access (EDCA) mechanisms employed by Wi-Fi, and has the following key features:

- A binary exponential back off procedure is used to initiate a new channel occupancy (CO) on the DL or UL. In 5 GHz, LBT is performed per 20 MHz sub-bands in frequency. NR-U devices must count down a random number of sensing slots (back off) as idle before transmission initiation, using ED at -72 dBm (or lower) to determine whether a sensing slot is idle or busy.
    - The contention window size (CWS) for the DL back off is adjusted based on hybrid automatic repeat request (HARQ) feedback from the user equipment (UE), and the CWS adjustment for a scheduled UL transmission is indicated in the scheduling grant. The initial CWS range is determined by the traffic priority class.
- Once a CO has been initiated, a responding device (either UE or next-generation node B (gNB)) can share the channel occupancy without performing LBT if the gap from the end of the previous transmission burst is at most 16 µs. Otherwise, a single sensing interval of 25 µs must be observed before CO sharing.
- Multi-carrier LBT involving multiple 20 MHz sub-bands has several flavors. The NR-U device may aggregate multiple 20 MHz sub-bands, or operate with a single bandwidth part that is larger than 20 MHz in frequency. Furthermore, the single-carrier LBT procedure can be performed individually on each sub-band. Or, the single-carrier LBT procedure with random back off can be performed on a designated primary sub-band while a single sensing interval is performed on the remaining sub-bands. In either case, the set of active sub-bands must coincide with the channel bonding sets used by Wi-Fi in the 5 GHz band. The spectral emission aspects of multi-carrier LBT are addressed in Section 2.3.

The sole exception to the use of random back off for CO initiation is the DL discovery signal (DS). The DS contains synchronization sequences and broadcast signaling that are essential for initial access, and are analogous to a Wi-Fi beacon transmission. The DS is a critical signal for standalone and dual connectivity deployments that should be prioritized for robust operation. Therefore, a gNB can initiate DS transmission using a single sensing interval of 25 µs as long as the DS duration does not exceed 1 ms, does not contain unicast data, and is not repeated with a periodicity of less than 20 ms.

An illustration of the DL LBT scheme is shown in Figure 2, where the gNB doubles its CWS due to decoding error and HARQ NACK reception from the UE. For transport block-based HARQ feedback within a single LBT sub-band, CWS is reset if at least one “ACK” is received, or at least one new data indicator is toggled in the UL grant for the transport blocks transmitted in the reference duration (typically the start of a CO).

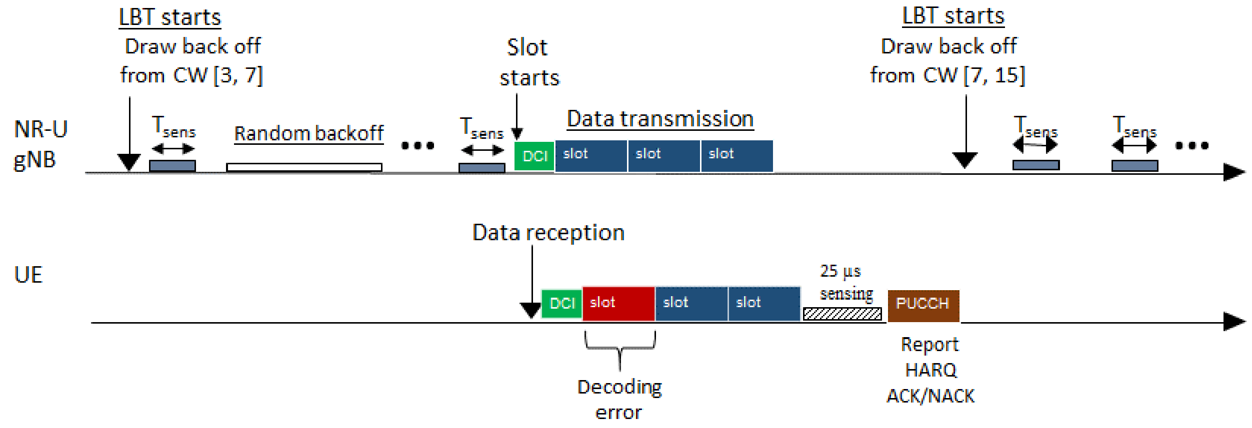

Figure 2 - Example of DL LBT with contention window size increase due to decoding error at the UE.

The framework described above was the basis for multiple NR-U and Wi-Fi coexistence evaluations during the Rel-16 Study Item phase. A majority of sources showed that NR-U is as good a neighbor – and in some instances a better neighbor – to a Wi-Fi network as another Wi-Fi network [1]. Some of the reasons for this are an increase in overall spatial reuse when Wi-Fi networks detect NR-U devices at -62 dBm as opposed to preamble detection at -82 dBm, and the use of UL scheduling in NR-U which reduces the number of nodes simultaneously contending for channel access.

2.3. NR-U: Higher-Layer Aspects

Applying the LBT mechanism takes care of the required coexistence for operation in the 5.150 GHz to 7.125 GHz unlicensed spectrum. However, the effect of avoiding transmission due to LBT failure could cause several mechanisms to fail. For instance, NR considers the possibility that the transmission of a random access channel (RACH) preamble (Msg1) may fail due to collision or due to the UE being at the cell edge. Such instances should be differentiated with the case where the UE fails to transmit Msg1 or Msg3 due to LBT failure. Otherwise, the medium access control (MAC) layer may unnecessarily increase power in the next Msg1 transmission, or MAC may reach the maximum number of Msg1 transmission attempts. There are instances, e.g., in scheduling request (SR) transmission, where the possibility of consistent LBT failures should be accounted for so that a UE does not reach radio link failure (RLF) state unnecessarily. This is mainly required for Scenario C where deployment is purely based on unlicensed spectrum, but it also helps operation in other scenarios.

NR-U added a procedure named consistent LBT failure to take care of the possibility of frequent LBT failures and let the MAC layer act accordingly if such event occurs. In this procedure, the MAC layer enumerates every LBT failure, whether it happens during a MAC-initiated transmission, e.g., Msg1 or SR transmission, or during a PHY initiated transmission, e.g., HARQ ACK or sounding reference signal (SRS) transmission. However, LBT failure enumeration is continued if the LBT failures are not too far apart (which is ensured by maintaining a configurable timer). If the number of LBT failures exceeds a configured threshold, the MAC layer declares consistent LBT failure (for the active bandwidth part). Then another UL bandwidth-part is chosen and a random access procedure is initiated; if no BWPs are left, higher layers are informed of the failure. In scenarios other than Scenario C, the MAC generates an appropriate error failure and sends it on the primary cell.

2.4. Radio Frequency Aspects

As mentioned in Section 2.2, the channel access framework for NR-U is based on the LBT mechanism. In order for this mechanism to coexist effectively with Wi-Fi, the RF characteristics of NR-U should be very similar to Wi-Fi.

To ensure that leakage energy in-band and out-of-band does not cause any more interference than a Wi-Fi device currently causes to another Wi-Fi receiver, the emission mask adopted for NR-U was equivalent to the emission mask of 802.11ax. Figure 3 shows the NR-U basic emission mask adopted by 3GPP.

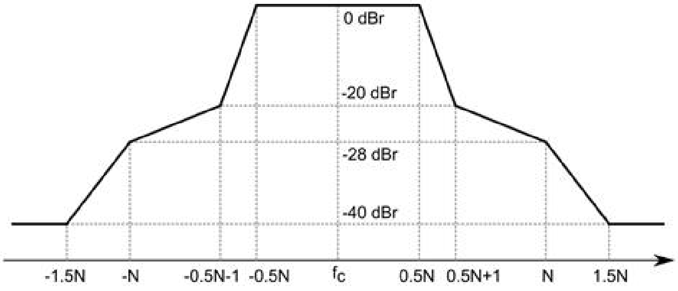

Figure 3 - NR-U basic emission mask

NR-U supports frequency-domain puncturing when operating in wideband operation. Wideband operation in NR-U means that a serving cell can be configured with a bandwidth larger than 20 MHz. Although this brings different advantages in terms of overhead and flexibility, it may introduce challenges from a coexistence and RF requirements perspective. In NR-U, channel access mechanisms (described in Section 2) using 20 MHz channel bandwidths ala “sub-bands” address one of the most critical co-existence challenges with Wi-Fi. Puncturing occurs when a channel failed clear channel access (CCA) in a 20 MHz sub-band.

There are various puncturing cases depending on the LBT successful outcome. The following summarizes the various puncturing cases and the floor limits that avoid in-band leakage interference.

Case 1: Single non-transmitted channel (N=20 MHz)

For the case where only one single non-transmitter channel fails CCA, the floor limit is -23 dBr.

Case 2: Two non-transmitted channel (N=40 MHz)

For the case where only two consecutive non-transmitter channels fail CCA, the floor limit is -25 dBr.

Case 3: Edge puncturing, two non-transmitted channels (non-consecutives) and more than two non-transmitted channels

For the case where edge puncturing, two non-transmitted channels (non-consecutives) or more than two non-transmitted channels, the spectral emission mask (SEM) is floored at -28 dBr.

Finally, to ensure co-existence between NR-U and Wi-Fi, the channel raster for NR-U needed to be aligned to the Wi-Fi channel bonding configuration. The Wi-Fi channel bonding configurations are 20 MHz, 40 MHz, 80 MHz and 160 MHz. For NR-U, channel bandwidths have been approved in 3GPP for 20 MHz, 40 MHz, 60 MHz and 80 MHz.

For 60 MHz bandwidth configurations, the channel raster was aligned to the 80 MHz Wi-Fi channel bonding configuration. In this way, an NR-U 60 MHz channel would fall inside an 80 MHz Wi-Fi channel, ensuring that fair co-existence prevails.

3. 3GPP 5G Core (5GC) Network integration of Wi-Fi Networks

Section 2 described how 3GPP NR-U co-exists with IEEE 802.11ac/ax technologies at the radio level. This level of integration is expected to be used for when two different operators employ the unlicensed spectrum in the same physical area. However, for when the same operator employs both these technologies (e.g., in different physical areas) then another form of technology integration described below can be used.

During the nascent stages of LTE and evolved packet core (EPC) definition, 3GPP had created a novel way of connecting radio access technologies (RATs) other than those created by 3GPP (referred to as “Non-3GPP Access”) e.g., Wi-Fi. The basic premise was that the management (control and user plane signaling) of Non-3GPP Access was left to the technology in question (e.g., via normal Wi-Fi signaling) (see [3]). Once the UE (or station (STA)) had acquired a local Internet Protocol (IP) address via the Non-3GPP Access, it would attempt to access 3GPP EPC. Depending on the relationship of the operator managing EPC to that of the one managing Non-3GPP Access (e.g., Wi-Fi), the Non-3GPP Access was categorized as either “trusted” or “untrusted.” The essential difference between the two was in how the UE was authenticated, and how UE interacted with EPC. For various reasons, the “trusted” Non-3GPP Access was not widely deployed. Untrusted Non-3GPP Access wherein an evolved packet data gateway (ePDG) was the gatekeeper of UE’s access via e.g., Wi-Fi to EPC did gain popularity especially due to support of voice over IMS (VoIMS) calls via Wi-Fi access (which colloquially came to be known as “Wi-Fi Calling”).

Then, 3GPP adopted some learnings from the architectures mentioned during the development of the 5G system (5GS). One impactful change was to bring mobility control-signaling (non-access stratum – NAS) from UE/STA to terminate at the same access and mobility management function (AMF) managing UE’s control-signaling when using 3GPP Access, i.e., a single control-signaling anchor point (see [4]). This allows for a loose-yet-tight-enough integration model.

4. Conclusions

As discussed in this paper, both NR-U and 802.11n/ac/ax had different design targets, and consequently different performance objectives. However, the marketing wars, which plague this arena, seem to pit NR-U (and to a certain extent LTE LAA) against 802.11n/ac/ax as adversarial technologies. The authors believe that while the traditional boundaries of ecosystem and service providers for both technologies were markedly different, the current climate of hybrid service providers begs for embracing a new era of thinking.

The authors believe that the choice of unlicensed technology is dictated by a plethora of factors such as deployment scenario, involved complexities, involved costs, performance requirements, differentiating between immediate vs. future need, etc. There is no such notion of "all things being equal" here. In all cases, certain factors play a decidedly dominant role in the eventual choice of unlicensed technology. The following are some examples of thoughts which could aid in making the right choice – and by that we mean, a choice that is right for your needs:

- Do I want a decent (say, 200 Mbps) data pipe to provide Internet access to my employees working in my indoor factory – because they aren't allowed to do so via office-provided equipment? If so, then choosing a technology (e.g., NR-U SA vs 802.11ax) which is simple to deploy may make sense for me. Simple has many connotations. Here, is my main worry about the complex RF planning required, or equipment availability, or ease of maintaining the network once deployed? Some may argue that the involved complexity for RF planning of an NR-U network is about the same as an 802.11ax network. Equipment availability (both end user device and base stations) is also the same, they said. They also said they can provide a System_In_The_Cloud for both technologies making the network operations a breeze. But, how much am I willing to spend on providing this "convenience" to my employees? In this case, a cost-conscious employer may decide on IEEE 802.11ax as cost becomes the dominating factor.
- Consider the same factory example, but now the employer has a need to manage a complex grid of autonomous guided vehicles (AGV) where a "hive-brain" topology is required. A target latency of 10 ms @ 3 m/s velocity is considered table-stakes. This is further limited by the fact that AGVs lack compute horsepower to calculate required trajectory to execute a particular task (move block A from Section X to Section Y) whilst avoiding obstacles (including other AGVs) and identifying Sections via QR code scanning. The dominating factor in this case becomes the technical constraints placed on the system. An unlicensed system which excels at synchronous coordination in both downlink and uplink directions is naturally better suited to meet this need. Hence, choosing NR-U SA may make sense
- One may argue that the inherent restriction in the previous examples biased it towards a single technology as the "winner" for respective use cases. What if there are cases where, for example, both NR-U and 802.11ax may check all the "needs" boxes? Let us change the first example by removing cost-restrictions. Either technology would then be a good fit. So, what should I do? Maybe factoring a future need is worthwhile? What if I'd like to pay (as a reward) for the end user device, and cellular services for my high-performing employees? A technology which allows seamless mobility from indoor to outdoor environments would then become the dominating factor. NR-U SA indoor with a seamless handover to LTE or NR (macro) outdoor with the same user credentials used for secure access in both environments would fit the bill.

In closing, the authors would like to emphasize that by its very nature, the two technologies (3GPP-based vs IEEE-based) are not sworn mortal enemies. We as an industry are partly at fault for creating such an image. And, only we as a collective can undo the damage. This paper is a small step towards that goal.

5. Abbreviations and Definitions

3GPP	Third Generation Partnership Project
5GC	fifth-generation core

CO	channel occupancy
CWS	contention window size
DL	downlink
DSRC	dedicated short range communication
ED	energy detection
EPC	evolved packet core
HARQ	hybrid automatic repeat request
LBT	listen-before-talk
LTE	long term evolution
IMS	IP multimedia subsystem
NAS	non-access stratum
NR	new radio
NR-U	NR-unlicensed
SRS	sounding reference signal
UE	user equipment
UL	uplink

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R-PHY DCA Telemetry Data Management

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

As consumers' demand for bandwidth increases, the service provider's access network platform is tasked with scaling accordingly. The number of nodes and service cores that make up the access network is increasing faster and in greater numbers than ever seen before. In the not too distant future, a service provider may deploy more nodes in a single year than they had in the entire network 10 years ago. This puts increased pressure on the tools, people, and processes used to manage the access network. New ways of doing inventory management, data collection, alerting, and troubleshooting need to be created. One such technique is to evolve access network telemetry, from pull-based to push-based, real-time streaming data.

This ability to gather and analyze near real-time data carries many precision and timing benefits when it comes to monitoring, alerting and providing trending analyses on the systems that provide consumer-facing services. However, while massive amounts of telemetry data are beneficial, they don't come without some challenges, that provided us with lessons learned.

In this paper, we:

- Describe the operational benefits of push-based telemetry data versus the traditional pull-based data from our industry's access networks.
- Describe the benefits and challenges associated with creating visualization dashboards for operational use.
- Provide use cases of tools that take advantage of the telemetry data. Additionally, we share some of the disadvantages we confronted when conforming the data to support the traditional legacy and point-in-time tools for monitoring and alerting.

2. The Operational Benefits of Telemetry Data Versus the Traditional Pull-Based Models

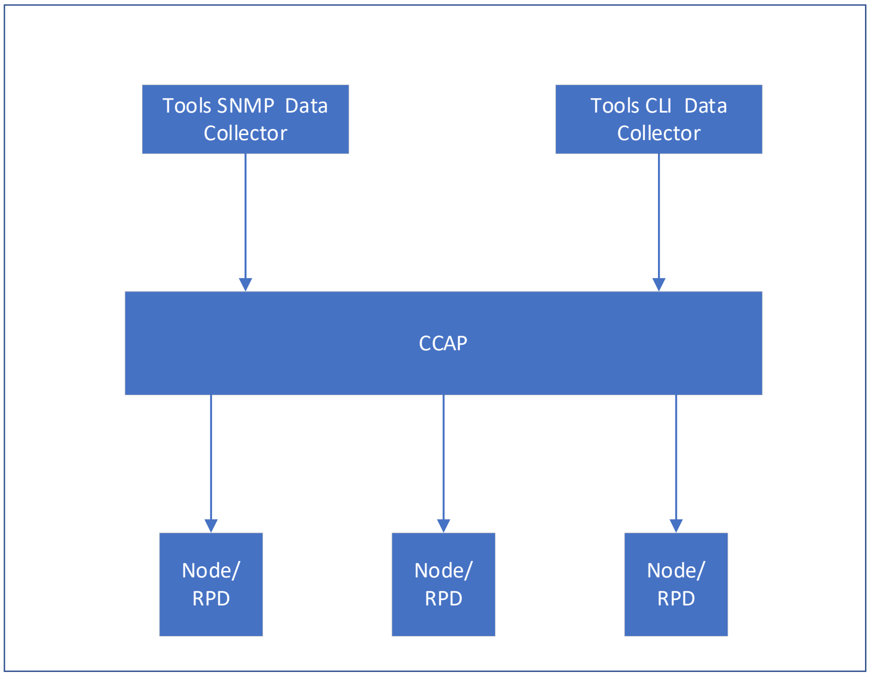

Figure 1 – Traditional access network data collection

Data consumers traditionally would pull telemetry data from the access network terminal or converged cable access platform (CCAP). The data consumers would have to keep and manage inventory of these devices. The administrator would have to grant access to each device to be able to collect data. Administrators would have two ways to get this data: One is via Simple Network Management Protocol (SNMP) and the other via command line interface (CLI). Either way, the data is collected periodically. Open source streaming data from Kafka helps with managing and maintaining multiple access points, plus it allows us to provide a single, standard method for providing and consuming the data. Streaming events and event consistency allow consumers to only listen to changes, while also getting all of the periodic updates, so as to stay in sync with the data. In our current environment with physical CCAPs we use periodic polling for collecting full inventory, which takes longer, and another, shorter polling cycle for collecting changes. The pull-based method only provides visibility based on the periodicity of the polling, meaning that certain events may be missed. With open source streaming data, event granularity is enhanced, because events are streamed in real-time.

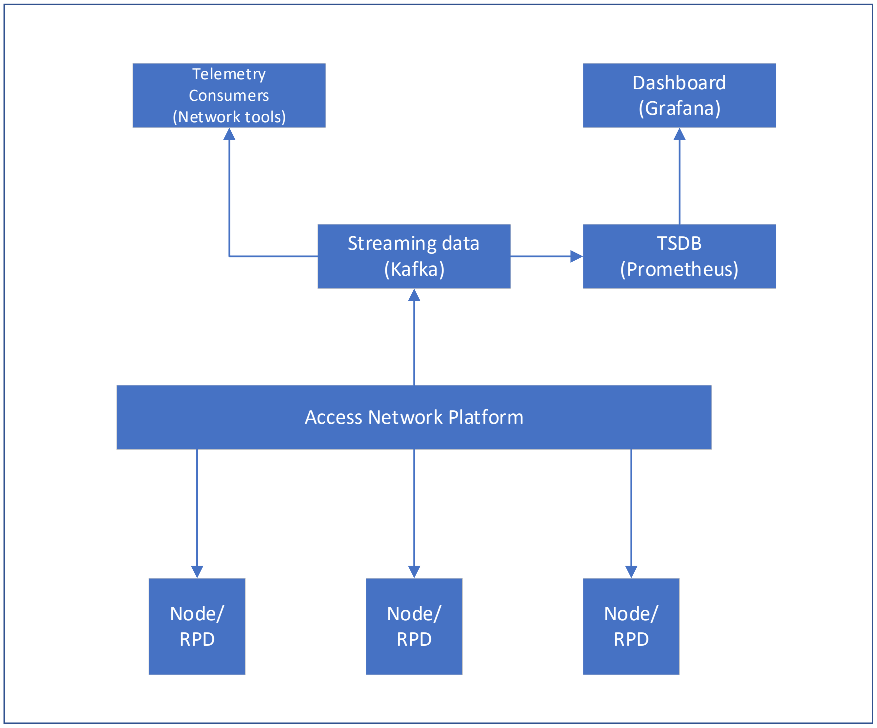

Figure 2 – Access network telemetry architecture

The benefits of telemetry data include:

- *The ability to discover inventory dynamically.* This may be advantageous to a fast-scaling distributed CCAP architecture (DCA). We may quickly deploy new access network terminals or nodes, without having the manual dependency of provisioning new inventory prior to deployment. When deploying DCA over hundreds of thousands of nodes per week, trying to manage inventory manually may quickly become an issue, especially if existing inventory management processes are insufficient. Traditionally, we maintained several systems that provide inventory of the CCAP, nodes, and cable modems and their associations. Each of these systems works by aggregating the data from its own data source, and then providing the desired associations. In DCA, we solved this by using a single source to periodically stream this data, which provides data consumers with inventory information from the DCA platform. This allows a single source to provide the data, regularly and accurately, for network technologists to receive and manage the changes based on the streaming data.
- *Faster and better change monitoring in the network.* Traditionally, when changes were made in the network, and if those changes impacted the network, we were required to rely on different systems and tools, each of which monitored its own specific elements to generate alarms. Additional time is thus required, to collect and correlate the different elements and alarms that could have impacted the network, based on the changes that were made. By contrast, with DCA telemetry we have a better and faster way to accurately monitor the network, especially when changes are occurring more frequently. For example, if speed tiers were added without approval, or if DOCSIS-level changes that were made that impacted services, alarms may be generated on the telemetry data that is continuously stored. Those alarms may be quickly correlated, at

regularly occurring intervals. Based on this trending analysis, alarms may be generated quickly to detect changes and alert operations about the changes that were submitted.

- *Proactive fine-tuning of the network.* From our experiences, the telemetry data allows an operator to be more proactive than the traditional reactive mode, especially when it comes to fine-tuning the network. We can use telemetry data, for instance, to build rules and create alerts that may nearly instantly resolve customer-impacting issues. If a fiber optic cable cut or power event results in a lost connection with a node, we may generate an alert to trigger a technician dispatch and an outage notification, to proactively inform customers and obviate an onslaught of help calls into customer care agents.

3. The Origins of DCA Telemetry Data

Several years ago, Comcast began to deploy our first internally developed CCAP instances. Different than a vendor-based physical CCAP these established an open source stream of telemetry data to a central repository located in Amazon Web Services (AWS), with all the metrics we knew were needed for existing tools, plus a large list of platform-specific tools. Due to the nature of this process, a significant level of discovery occurred, including the selection of tools for visualization and alerting on this data. At the time, the existing operational visibility systems internal to Comcast were not configured or configurable to ingest and process this data, so we had to find or make our own. Some of the earliest choices were Prometheus as the time-series database (TSDB) and Grafana, an open-source metrics analysis platform, for visualization of the data.

4. Telemetry Visualization: The Good and the Bad

When we first stood up Grafana, some of the questions we asked ourselves were:

1. What data needs to be visible to understand the health of the system?
2. What else do we have in the streaming data set that could be useful?

This led to the creation of several dashboards – some of which were useful and others not so much. One benefit we saw with the wealth of data is that we could very quickly begin to track the metrics associated with a given operational problem. For example, early on we experienced an issue with DHCP v4 offer processing. Because we had ~7000 metrics flowing into our data store, we were able to graph the pertinent DHCP data in less than an hour, which provided insight into the behavior for the operational teams. Another positive outcome was the ability to see things like the start time of an event reflected in the graphs in much more granular detail than before. These metrics were being published every 15 seconds, whereas the existing charting systems were (at best) five-minute polling intervals.

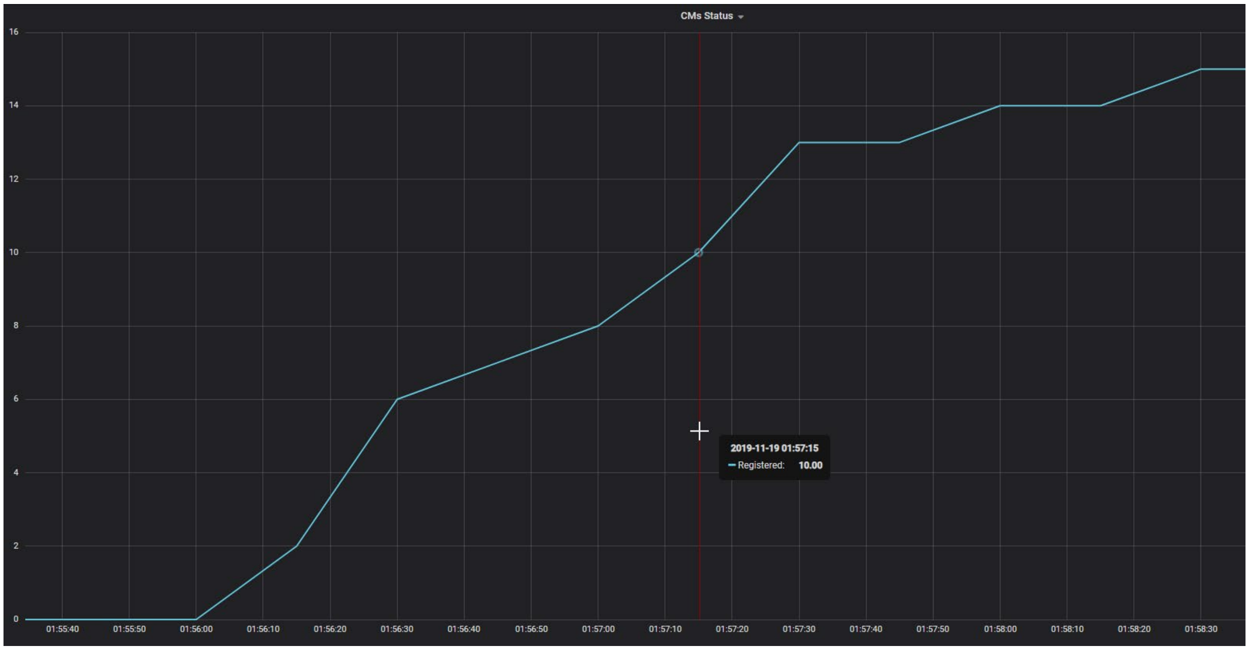

Figure 3 – Graph of 15 second data slice following a software upgrade, showing the granular details of cable modems coming online

A downside that occurred was the perhaps inevitable "embarrassment of riches" when it came to the metrics. This resulted in the creation of graphs and dashboards which ended up being less than actionable, and ultimately more of a distraction from the core operational issues that needed focus. For example, we charted service flows per media access control (MAC) domain, with the intent of being able to detect more subtle problems that may impact voice services. Those never ended up being used, and just cluttered up the views required for more actionable data. In retrospect, we should have stayed more focused on the central problems of any day, namely stability and scaling.

5. The Benefits of a Central Repository of Access Network Telemetry Data

As we added more instances serving real customers, we began to connect our existing operational monitoring systems up to the central AWS data repository. We were using Kafka to distribute the data to other Comcast departments, and this made it very easy to quickly connect other teams to the data they needed. Also, for the vendor-based and physical CCAPs each monitoring system that needed periodic metrics would generally query via SNMP. This led to issues like multiple teams hitting the CCAP for the same data points, which was neatly solved by the streaming model. In this case, we aggregated all the data into one pipeline, to which any arbitrary number of consumers could connect and take what they needed. Additionally, this reduced the actual and potential impact of various tools and teams polling (sometimes over-polling) the CMTSs.

6. Adoption of Streaming Data by Existing Applications

Another of the challenges we faced in this new data method, with its vastly improved delivery interval, was its adoption by the existing tools ecosystem. Systems that had evolved in a pure pull environment were typically constrained by how frequently they could (or couldn't, more accurately) pull the desired metrics from the network. Since their internal data pipelines were scoped for a specific volume and periodicity, they found it very challenging to make use of the more frequent data that could come from a push system. For example, a system that took 10 minutes to poll the entire network struggled with how to adapt to a data stream that contained the same data – but arriving every 15 seconds.

Over the last several decades, many tools were internally developed at Comcast or bought from vendors to help address the various challenges of keeping a nationwide hybrid fiber/coax (HFC) network functioning well. These were all oriented towards the SNMP-pull model, and faced significant technical and process challenges, particularly with increasing network scale, which had to be addressed before they could take advantage of the more granular streaming data.

One example: An operational visibility team ended up de-sampling the 15 second data push down to the interval their application was accustomed to handling (which refreshed data in five-minute intervals.) This was required because the internal structure of the application was not geared to respond to that push rate. Additionally, we discovered that with data coming in that frequently, we were exposed to micro-events that we previously could not "see." This meant that the application would show modem offline events that could not have been seen when the operational state was being captured only once every five minutes. That caused the application to alert at a much higher rate than before, which caused user and organizational complaints about the actionability of the new alert volume.

The conclusion that we drew from this was that while high-rate telemetry data may provide a much more complete and timelier picture of the state of the network, there were other considerations that had to be addressed before turning it on and declaring victory. Specifically:

- Can the existing downstream applications consume and make effective use of the higher data rates?
- What impact may this have on their event/issue detection algorithms and thresholds?
- How will the human processes be affected by this level of visibility?

7. Streaming Telemetry Use Case Example

One use case that helped solve certain problems that arose in the pull telemetry environment was that of modem inventory: How we might have continuous, near-real-time visibility into what DOCSIS devices were in which states, on every MAC domain that supported the streaming telemetry architecture.

In a streaming environment, we may push all the evaluation logic and intelligence outside of the CMTS properly, allowing for as much subtlety of assessment as desired, unbound from the core platform. The CMTS is only responsible for emitting the data that will be evaluated, and therefore we spare it the additional processing load that would be needed for, say, systems that still use SNMP traps.

8. Conclusions

In this paper we discussed how DCA has benefitted from the telemetry data that is streamed periodically and accurately using an open source system. We discussed how streaming of the data has been very advantageous, compared to the traditional polling of the access network data when alerting, monitoring, and visualizing the network.

With the benefits, we also encountered challenges. Some of them involved storing and creating the visualization dashboards. We also explained the benefits and challenges of having a single and central repository of the network data. In closing, we hope that providing this insight to some of our use cases will help benefit others and help evolve the future for providing a continuously improving customer experience.

9. Abbreviations and Definitions

9.1. Abbreviations

AWS	Amazon Web Services
CCAP	converged cable access platform
CLI	command line interface
CMTS	cable modem termination system
DCA	distributed CCAP architecture
DHCP	Dynamic Host Configuration Protocol
DOCSIS	Data-Over-Cable Service Interface Specifications
HFC	hybrid fiber/coax
MAC	media access control
PHY	physical layer
RPD	remote PHY device
R-PHY	Remote PHY
SNMP	Simple Network Management Protocol
TSDB	time series database

9.2. Definitions

Grafana	A multi-platform open source analytics and interactive visualization software
Apache Kafka	An open-source, low-latency platform for handling real-time data feeds
Prometheus	An open-source monitoring system with a dimensional data model, flexible query language, efficient time series database and modern alerting approach

Designing Operating Models for Serving Enterprise Markets

Charting the Way from Novel Business Models to Cable Industry Operating Models

A Technical Paper prepared for SCTE•ISBE by

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1. Introduction

With the emergence of the fourth industrial revolution, enterprises are realizing that information and communication technology (ICT) is not just a support function, but an enabler to drive their future innovation. This opens opportunities for multiple system operators (MSOs) and independent system operators – both known more generally as cable operators – to support enterprises in their service areas to transform into digital organizations by leveraging ICT to transform their operational technology (OT). Cable operators can also explore a new set of services they can offer to enterprises, building upon their network reach and close end customer relationships. The new services often require new business models and drive business model innovation activities.

This paper presents and examines several business models that allow cable operators to participate with third parties and enterprises in different value clusters across various industry verticals, focusing on synergies with the cable operator's current business models. These business models are characterized by target customer segments, customer relationships, revenue streams and key partnerships. To provide the capabilities that are required by these business models, a cable company needs to establish a fitting operating model.

The business models are benchmarked against each other to establish the most efficient way a cable operator and an enterprise can partner while at the same time satisfying one or more of the following characteristics:

- Connect to high volumes of devices
- Limit reaction time from sensed changes to corresponding activities
- Capture high volumes of transactional data (often real time) to analyze and derive valuable information
- Near zero susceptibility to failures
- Rapid reconfiguration of operational technology

To enable high efficiency, remove friction and increase value-add, while supplying the above characteristics, the projected operating models need to support a high degree of automation across their different activities and across the end-to-end service delivery chains.

The rest of this paper is organized as follows:

In Section 2 we provide a brief overview of the evolution of telecommunication-enabled services and the demands it creates for business model innovation. Section 3 provides analysis of different kinds of business models applicable to cable operators. In Section 4 we examine the implications of these business models for the cable industry's operating models. Section 5 presents the application of selected business models and associated operating models to three different enterprise domains. In Section 6 we present our conclusions.

2. Evolution of Telecommunication Enabled Services

Massive digital transformation across the industry segments and the deployment of 5G are enabling the creation of many new services, including services that require very low latency and/or high bandwidth, [10].

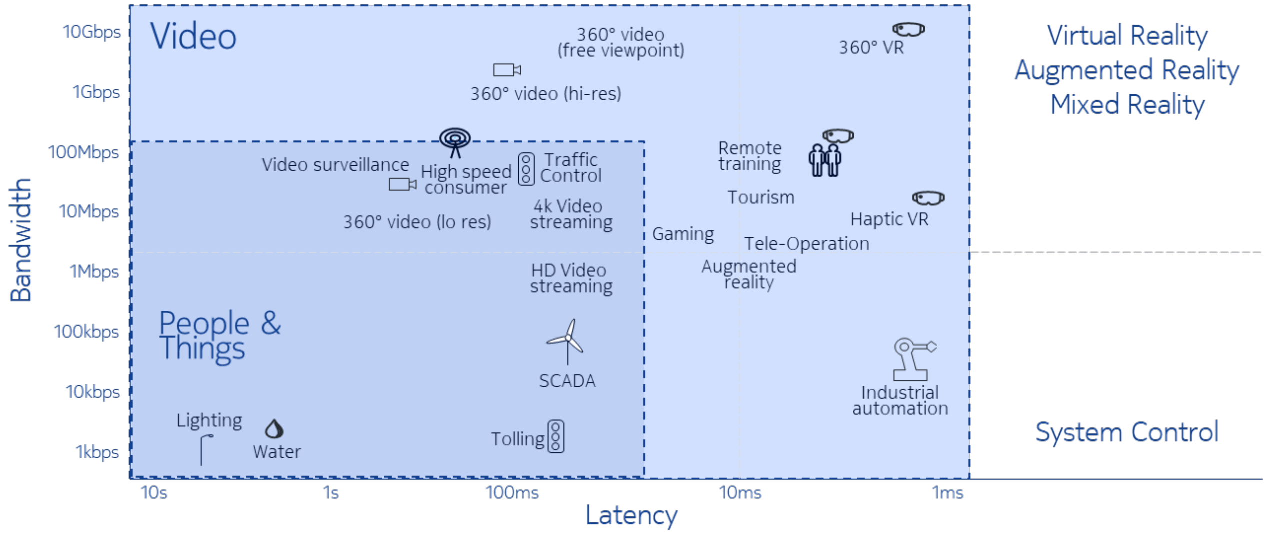

Figure 1 - Telecommunication enabled services

Figure 1 is a (non-exhaustive) illustration of existing and upcoming telecommunication enabled services that are relevant for the cable industry.

These services are provided as a combination of new and more performant telecommunication services (e.g., 4G, 5G) in combination with huge volumes of data (sourced by IoT), new computing architectures (cloud, microservices), innovative paradigms (artificial intelligence / machine learning) and corresponding operating models, [8] and [9].

In many of these cases cable companies are well-placed to support these services as they already have the necessary enabling infrastructure close to the customer. Operators can support these services either by partnering with others or providing the service going alone as reflected in the business models described in Section 3.

3. Business Models

Cable operators have traditionally focused on providing reliable connectivity, video, voice, and data services. They have now recognized that consumption patterns are rapidly changing, value is moving to other stages in the service provider value chain and that completely different markets have emerged. As a result, the traditional business models have come under increasing pressure to change, driving the industry to innovate and build the capacity and agility to deliver new classes of services to new markets, domains, and enterprise customers.

As discussed earlier, broad adoption of cloud and the spread of new and emerging technologies such as 5G, artificial intelligence (AI) and the Internet of Things (IoT) have opened up opportunities for operators to offer new services and establish new revenue streams, while establishing partnerships, building a loyal customer base, and creating solid competitive advantage for years to come.

A business model has three interlinked components, [13]:

- Value proposition reflecting corporate vison and targets (markets, customer segments, products and service ranges)
- Revenue model guiding the interactions in the new value ecosystems (customer relationships, partners, distribution channels, value networks and payment structure)
- Cost base and value creation and delivery, shaped by innovation and largely dependent on the operating model (core assets, core processes, people, culture, organizational structure, partnerships).

We introduce a framework of three reference business models that are viable for cable operators in the current business environment, see Figure 2[1]:

1. At present, most operators provide connectivity to other entities in the value chain ("Connectivity Provider"), thus enabling OTTs to deliver their services to the end consumers.
2. The next step is the "Digital Service Enabler," where, in addition to providing connectivity, operators also provide foundational services to other entities, which in turn deliver complete solutions to their customers.
3. The final step is becoming a "Vertical Solution Provider," in which case the cable operator covers the complete value chain.

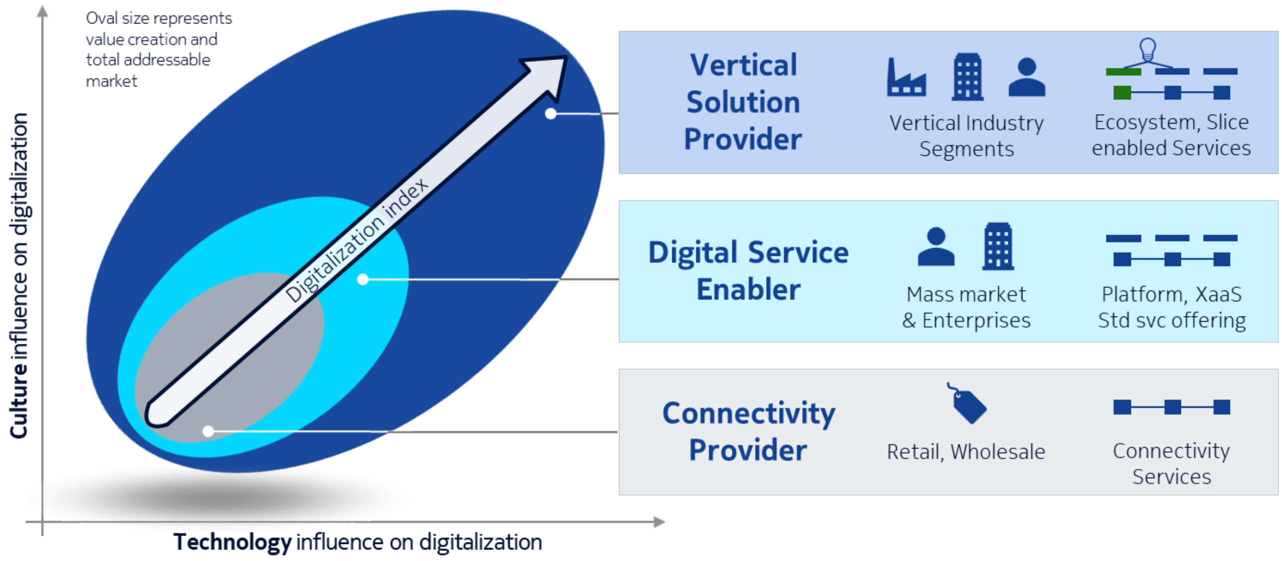

Figure 2 - Viable service provider reference business models

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[1] Also illustrated on Figure 2 is that different reference business models are associated with different levels' of technology impact on digitalization.

These reference business models can be instantiated as a number of business model blueprints that differ in the scope and number of supported services, selected partnership model or, for example, the utilization of managed service providers (MSPs) to complement their own capabilities. Four such business model blueprints are discussed in more detail later in this section, namely: “bit pipe provider,” “infrastructure provider,” “platform provider,” and “solution provider.” Based on its strategic objectives and capabilities, any service provider can use a combination of business model blueprints as part of its overarching business model.

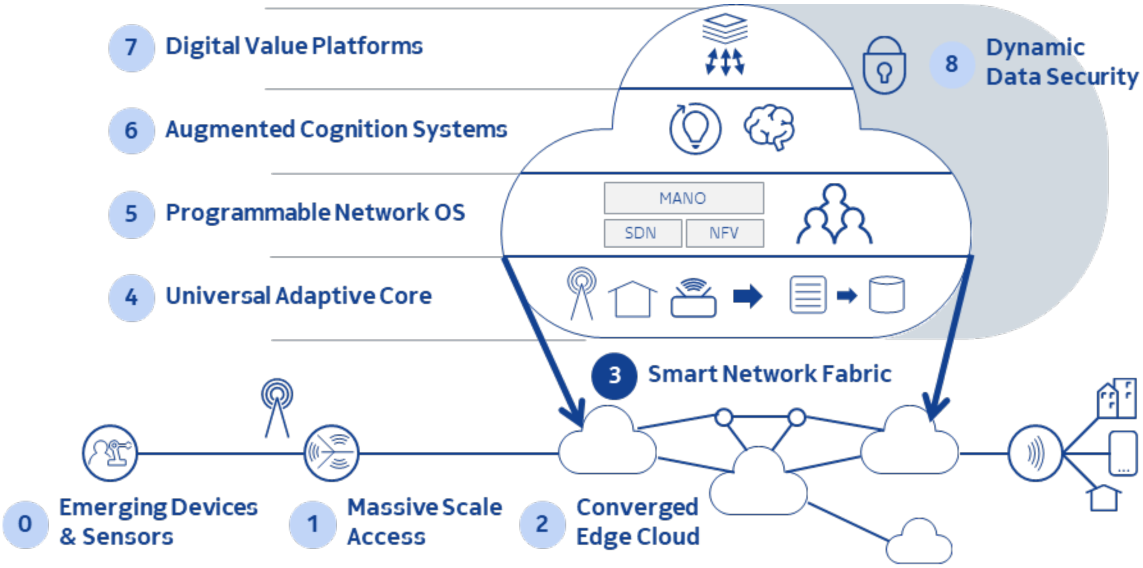

Figure 3 - Future X network architecture

The reference business models and related blueprints assume different levels of control and responsibilities for the network functions, services and applications in scope. To reflect this view we correlate them to the Bell Labs Future X (FX) network architecture (Figure 3), which defines a set of domains of responsibilities within and in conjunction with networks, see [3] and [11].

Table 1 - Analysis and delivery components

ID	Name	Description
A	Device	The user’s end device, e.g., an IP connected video camera
B	Access	The access network connecting the end device to the edge of the network (also referred to as the “edge”).
C	Cloud Infrastructure	Cloud infrastructure / infrastructure as a service, i.e. basic computing infrastructure including host operating system, virtualization, storage as well as datacenter interconnect.
D	Cloud Platform	Cloud platform layer which is based on C (cloud infrastructure) and adds platform components that can be reused over different applications either in a single or several domains.
E	Network	Core communication network except the access network.
F	Applications	The complete functionality of the application.
G	Network Security	All security components related to the network (access and core).
H	Application Security	All security components related to the application.

To structure the analysis and characterization of the selected business model blueprints we introduce the set of analysis and delivery components described in Table 1. These components are correlated to the FX architecture domains to check for coverage and completeness as shown in Figure 4. Some of the FX domains are split while others are combined in this mapping in order to achieve the level of granularity needed for our analysis.

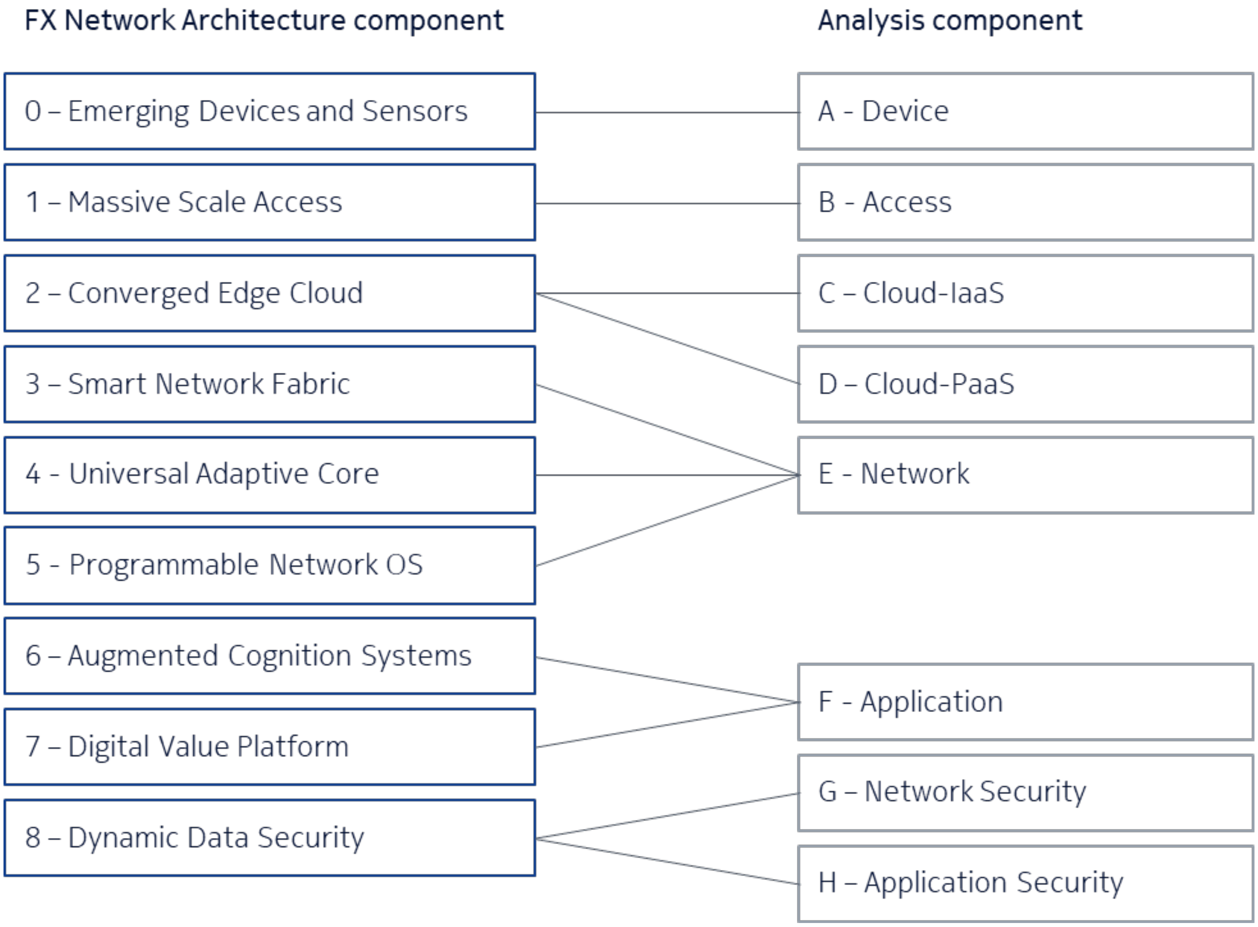

Figure 4 - Mapping of FX network architecture components to analysis and delivery components

As discussed in [1] and [2] a business model is a “useful lens for understanding a company’s logic because it describes what value is provided, how this value is created and delivered, and how profits can be generated therefrom.” Different business models have different implications for the corresponding operating models.

Next, we concentrate on the variations in the value creation and delivery approach aspects of the selected business model blueprints, which have the most significant impact on the operating models. We start by assessing the business model blueprints in terms of distribution of accountability for the analysis and delivery components *A through H*, among the set of key entities participating in the value chain, i.e., User, Vertical (enterprise) and MSO (cable operator), defined in Table 2.

Table 2 - Participating entities differentiated in the business model blueprints

Entity	Description
User	The end user, a consumer or an enterprise, whose needs are met – e.g., a household with a meter in the case of electricity market, a healthcare professional or a patient in the health market and a factory worker in a manufacturing setting.
Vertical	The organization that has traditionally delivered the services that meet the end user's needs – e.g., electric utility, hospital or a manufacturing plant.
MSO	Network operator providing multiple services.

The business model blueprints[2] examined in this paper are characterized in Table 3, based on the participating entities and their accountability for the analysis and delivery components. As an example, consider an operator that utilizes a hybrid cloud with private and public components to deliver greater cost flexibility by shifting workloads taking into account the locations of the logic and data – see Table 3, Analysis and Delivery Component D – Cloud Platform. (Notice that the blueprints, as defined, do not preclude the option of contracting out parts of responsibilities of one party, e.g., outsourcing the actual work on application operation components to a 3rd party as long as the control over it remains within the responsibility of the original entity.)

Table 3 - Business model blueprints—distribution of accountability per analysis and delivery component

Analysis and Delivery Component[3]	BM 1 "Bit pipe provider"	BM 2 "Infrastructure provider"	BM 3 "Platform provider"	BM 4 "Solution provider"
A – Device	User	User	User	User
B – Access	MSO	MSO	MSO	MSO
C – Cloud Infrastructure	Vertical	MSO	MSO	MSO
D – Cloud Platform	Vertical	Vertical	MSO	MSO
E – Network	MSO	MSO	MSO	MSO
F – Application	Vertical	Vertical	Vertical	MSO
G – Network Security	MSO	MSO	MSO	MSO
H – Application Security	Vertical	Vertical	Vertical	MSO

Figure 5 illustrates the distribution of responsibilities and accountability between the cable operator and vertical entities in each of the business model blueprints.

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[2] For the purposes of the analysis done in this paper, the "Digital Service Enabler" reference business model (illustrated in Figure 2) is divided into two business model blueprints - "Infrastructure Provider" and "Platform Provider" to better align with common cloud-related (business) models – IaaS and PaaS.

[3] Each analysis and delivery component represents all of its constituent components (physical and/or virtual) as well as the operations functionality required to run it.

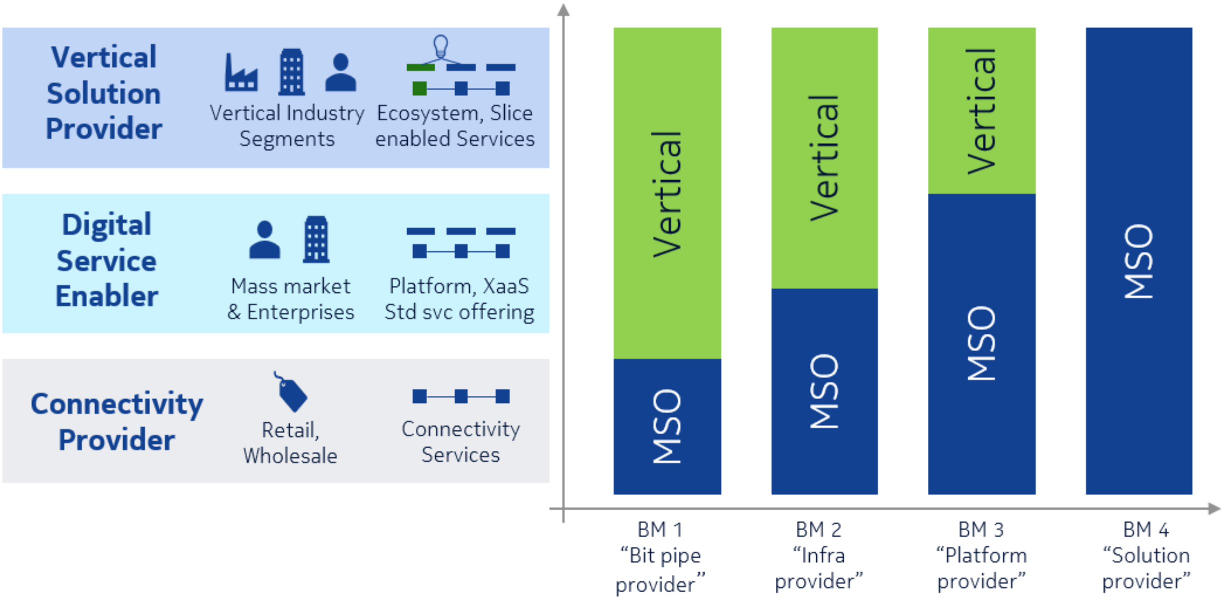


Figure 5 - Responsibility relation for the different business model blueprints

3.1. BM 1 "Bit Pipe Provider"

The "bit pipe provider" blueprint represents the classical (reference) connectivity provider model with clear delineation of accountability and responsibilities with respect to the outlined analysis and delivery components. Over the bit pipe provided by the operator, a vertical provider can host a cloud facility near the edge of the access network and operate its applications within that cloud. In a similar way, Google Stadia [5] and [6] runs over the "bit pipes" of connectivity providers. This model is prevalent today where cable operators remain connectivity providers.

In our analysis this model blueprint is used as a base, where advantages and disadvantages of other model blueprints are evaluated in relation to it.

3.2. BM 2 "Infrastructure Provider"

In this cloud-centric business model blueprint the operator takes over the ownership and responsibility for the cloud infrastructure and acts as an infrastructure as a service (IaaS) provider, managing the computing and storage infrastructure, including hardware, host operating system, hypervisors and management tools. The IaaS layer also provides high-level APIs used to abstract various low-level details of underlying network infrastructure like physical computing resources, location, data partitioning, scaling, security, backup, etc. Pools of hypervisors within the cloud system can support large numbers of virtual machines and offer the ability to scale services up and down according to customers' varying requirements.

Typically IaaS involves the use of a cloud orchestration technology like open stack and Apache CloudStack. It manages the creation of virtual machines and decides which hypervisor (i.e., physical host) to start it on, enables VM migration features between hosts, allocates storage volumes and attaches them to VMs, provides usage information for billing purposes and more. IaaS can also provide support for containers and Kubernetes to further enable the deployment of cloud native applications.

Since cable operators already have facilities close to their subscribers (the hub locations at the edge of their networks), they can capitalize on this advantage and reuse these locations for operating edge cloud data centers. This will allow them to efficiently move close to the subscriber workloads that would impose a heavy communication load on the network if run in a central cloud location, while still having the opportunity to utilize a central cloud if the edge cloud gets overloaded.

3.3. BM 3 "Platform Provider"

In this business model blueprint the operator takes over the ownership and responsibility for the cloud as "platform as a service" (PaaS) provider, offering computing infrastructure including common functional components and services such as databases, blockchain components, machine learning models, or other reusable application or domain-focused components, [14]. This blueprint provides a cloud-centric platform view and not a general platform business model, see [4], [11], [15] and [16].

The platform components can be reused over several applications, optimizing revenue to cost. This applies to generic components but could also cover components that are provided and optimized to satisfy the needs of a specific application/enterprise domain, e.g., healthcare domain, thus enhancing the value operators can deliver to those domains.

3.4. BM 4 "Solution Provider"

In this business model blueprint the operator takes over the ownership and responsibility of the complete service-value chain. This allows for efficient implementation of service management as the complete creation and delivery fabric is owned by one party from an operational perspective. While attractive and gaining popularity among leading MSOs [12], this model comes with its challenges as it requires high specialization in specific vertical domains, including understanding of the available applications and their lifecycle. Building skills in several domains would be a significant challenge for most operators, but the rewards could justify its implementation for selected high value use cases.

4. Operating Models

4.1. Impact of the Business Model on Operating Model Blueprints

This section shows the impact of the identified business model blueprints on the operating model along five aspects:

- **Integration**: Effects due to the interrelation of different elements (network infrastructure, platform and application) leading to different kinds / levels of operational efficiency for different business models.
- **Scale**: Effects due to scale, e.g., utilization of the same (development, operations, etc.) effort over a broader set of customers. One typical example is the reduction of (development) cost per user if an application is developed for a larger target group.
- **Specialization**: Effects (e.g., efficiency) that are enabled by a higher degree of specialization of staff while maintaining a certain minimum level of available / on call staff for each specialization topic.
- **Skilling**: Impact from the domain-specific skills required by personnel developing / operating at a certain layer. High demands on domain-specific skills lead to a low ranking in this category due to the specific efforts required.

- **Performance**: Performance of the application as it appears to the end user. This focuses on end-to-end network performance metrics like latency, reaction speed, bandwidth.

A qualitative overview is shown in Figure 6 with the differences described in more detail in the following sections.

Aspect	BM 1 "Bit pipe provider"	BM 2 "Infrastructure provider"	BM 3 "Platform provider"	BM 4 "Solution provider"
Integration	~ (Reference)	~/+	+	++
Scale	~ (Reference)	+	+	+
Specialization	~ (Reference)	~	+	+
Skilling (focusing on domain specific skills)	~ (Reference)	~	~	-
Performance	~ (Reference)	+	+	+

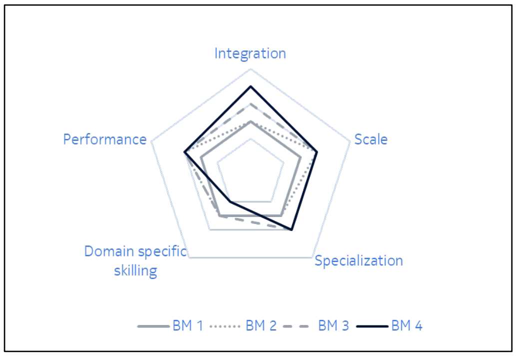


Figure 6 - Operations impact summary

4.1.1. BM 1 "Bit Pipe Provider" Implications

This is the basic model. The properties of all other business model blueprints will be reflected relative to this one.

It is worth noting that migration to newer technologies, e.g., DOCSIS 3.1 or XGS-PON, will occur concurrently with the move to service the needs of enterprises. This technology evolution will call for new competencies and enable fundamentally new use cases. However, as a bit pipe provider, the cable operator's challenge will be to ensure operational readiness and to manage the challenges of fulfillment, assurance and billing while both legacy and new technologies are in service. The impact on the five aspects will not be disruptive and likely be similar for all business model blueprints.

4.1.2. BM 2 "Infrastructure Provider" Implications

The operator controlling the infrastructure and corresponding management is able to utilize scale effects leading to better average utilization of the deployed infrastructure. Processing can be moved to the most cost- and performance-efficient location considering computation as well as communication cost or effort.

The ability to move computation closer to the end device also improves the performance of the service, especially for data intensive services, e.g., those based on video analytics, in terms of a reduction of the (average) latency until conclusions can be drawn.

Additionally, scale effects can be gained compared to other approaches as or if the operator is utilizing the same infrastructure for multiple verticals.

4.1.3. BM 3 "Platform Provider" Implications

With the cable operator also being responsible for the platform additional effects become viable.

Conceptionally all “XaaS” models are based on the principle of isolation between the different layers (network, infrastructure, platform, application). In practice this isolation is never fully established, leading to impacts that the different layers have on one another.

With the operator being responsible for network, infrastructure and platform, more of the layers are managed by the same entity which makes alignment and optimization across layers easier. It also enables better coordination of roadmaps between different layers which reduces the testing effort as the number of test-cases can be limited to the scenarios that are actually deployed – which can be minimized by coordination of the roadmaps, leading to benefits on the integration aspect compared to BM 2.

For BM 2 we have shown no specialization benefits. This was driven by the assumption that each vertical operates enough infrastructure to have reasonably specialized staff. This assumption does not hold for the more diverse platform layer. Hence the move of the responsibility for the platform layer from the vertical to the cable operator leads to a higher degree of specialization of staff for the platform components by having larger and bigger platform assets taken care of by the operator, leading to the specialization benefits shown in Figure 6.

4.1.4. BM 4 “Solution Provider” Implications

The addition of the application to the responsibilities of the operator extends the same kind of improvements explained in Section 4.1.3 to the application layer.

On the flip side these advantages come with the aspect of the application requiring domain-specific skills that will be difficult to obtain for more than a few domains. A reasonable approach here may be the selection of few strategically chosen domains where the operator obtains the required skills on the application layer while using a partnering approach for others, i.e., partnering with experts in the respective domain that provide the application to vendors. As with any of the business model blueprints, operators will need to make strategic decisions about which blueprints work best for them and to develop their resources and capabilities accordingly.

4.2. Operating Model Requirements

The role of operations needs to expand beyond the traditional definitions to support the evolution of the business model. Cable operators need to drive operation while balancing between cost efficiencies and value creation based on the role the operator plays in the overall value chain as discussed earlier.

This section discusses how operators need to adapt their network management functions to support “XaaS” models.

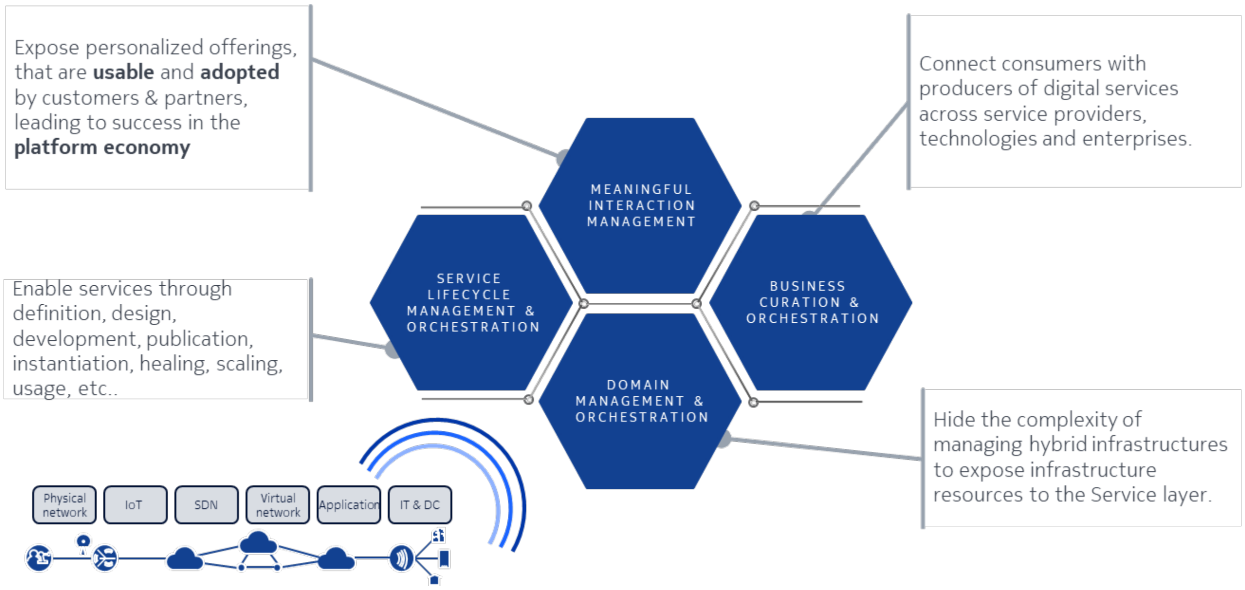


Figure 7 - Digital operations framework

The Bell Labs Consulting Digital Operations Framework as shown in

Figure 7 highlights four key areas operators need to focus on and strengthen.

For BM 1 ("bit pipe provider"), the most relevant component is domain management and orchestration. Optimizing this component will lead to improved operational efficiency, enabling services to be provided at the lowest cost possible, thus improving the value / cost relation. Service lifecycle management and orchestration as well as business curation and orchestration do have some effect on this business model as well; nevertheless, their importance massively increases moving towards BM2 "infrastructure provider" and BM3 "platform provider" which are much further intertwined into the overall delivery of business value.

BM4 ("solution provider") leads to high prominence of the "meaningful interaction management" component as the operator is going to become responsible for the interaction with the user.

Figure 8 highlights the required evolution of different process flows to support the journey towards becoming a digital service provider.

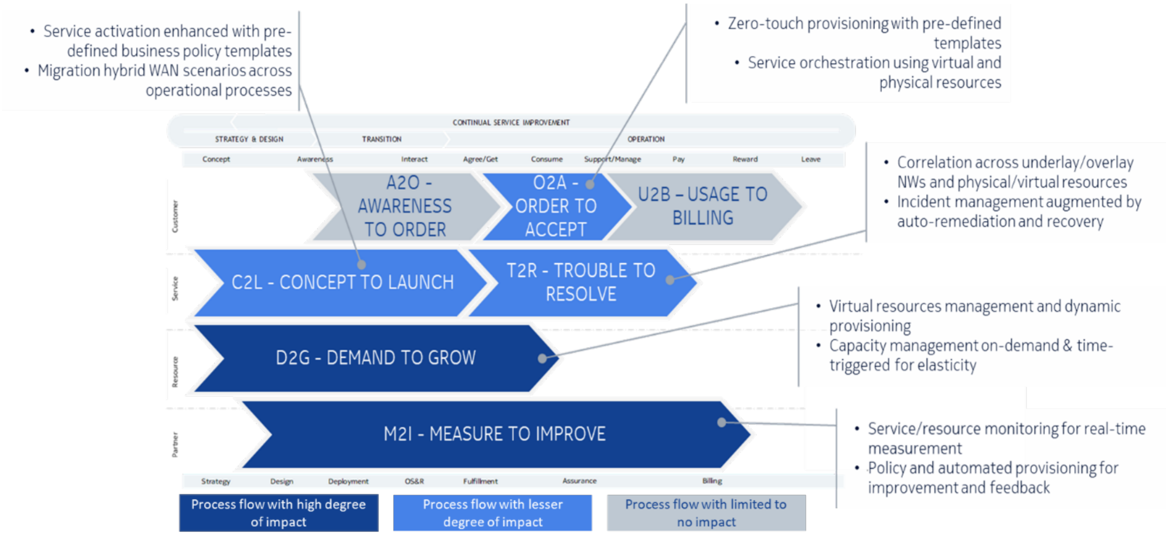


Figure 8 - Impact across operations process flows

The next paragraphs cover key underlying topics in a higher level of detail:

- **Correlation across underlay / overlay networks and resources**
  Automated correlation of alarms across overlay / underlay networks and resources utilizes comprehensive modeling of the deployed service instances (service models). The end state of such automated correlation is the identification of the root cause of an incident.
- **Auto remediation and recovery**
  Utilizing the identified root cause for auto remediation and recovery, operations applies appropriate means to restore services to the customer. This may require heavy interaction between different parties being responsible for different service delivery layers, depending on the business model.
  For efficient remediation and recovery, interactions across respective interfaces need to be highly (close to fully) automated. The heavy use of IT-based automation results in avoiding the need for human interaction which may otherwise lead to processing delays as well as the risk of manual error.
- **Service and resource monitoring**
  Service and resource monitoring needs to be based on the service models leading to a kind of comprehension of resource utilization and performance against the policies defined within the service design itself considering a dynamic environment.
- **Policy and automated provisioning**
  The perception of the current situation gained by service / resource monitoring needs to be translated into actual activities being executed on the network. When these activities can be automated, they are directed by policies that trigger automated actions such as provisioning.
- **Virtual resource management and dynamic provisioning**
  Driven by measurements of the actual utilization of physical and virtual resources, those resources will be scaled up or down, triggered by the related policies. Scaling up resources can be done by either adding capacity to existing virtual resources or spawning new virtual resources. This functionality can also decide on the relocation of resource instances to improve service quality (reaction time, reduction of network load, etc.).

- **Zero touch service management**
  Service activation is done using new service templates that can thereafter be used for zero touch provisioning. Zero touch provisioning enables the decomposition of customer facing services to resource configurations by utilizing service templates. Therewith this becomes the instantiation of a service model for a new user without the need for manual interaction.
- **Intent based automated orchestration and closed loop assurance**
  Guided by the business intent, service performance is monitored and validated in real time to ensure that corrective actions like traffic redirection, capacity scaling/descaling, notification, etc., are taken to meet the SLA and performance guidelines defined towards end user experience.

Based on the identified business model driven by the corporate strategy, focus of the process flow will shift from efficiency to value creation. Figure 9 showcases the shifting focus from BM1 to BM4. In BM 1 as a connectivity provider the focus (and actually the only main lever) is the efficiency of the service. However, the key is not just to look at small steps for cost reduction through islands of automation. Cable operators need to look at converged efforts. A tier 2 MSO from the North America region started with multiple automation projects running in siloes but realized that the individual projects failed to produce tangible results. They analyzed ongoing automation project considering opex impact. The results established that while ongoing project would have only 5-7% impact on full-time equivalents (FTEs), two additional projects would be able to provide additional 13-17% efficiencies.

Moving to BM 2 (digital service enabler) the operator can also take over more responsibility for the quality of the service by moving towards end-to-end.

The evolution to BM 3 introduces a market focused element into the portfolio of the cable operator, as the operator in this model becomes more tightly coupled to the application domain. In BM 4 (digital service provider) the operator finally has full control over the value fabric including the creation of demand.

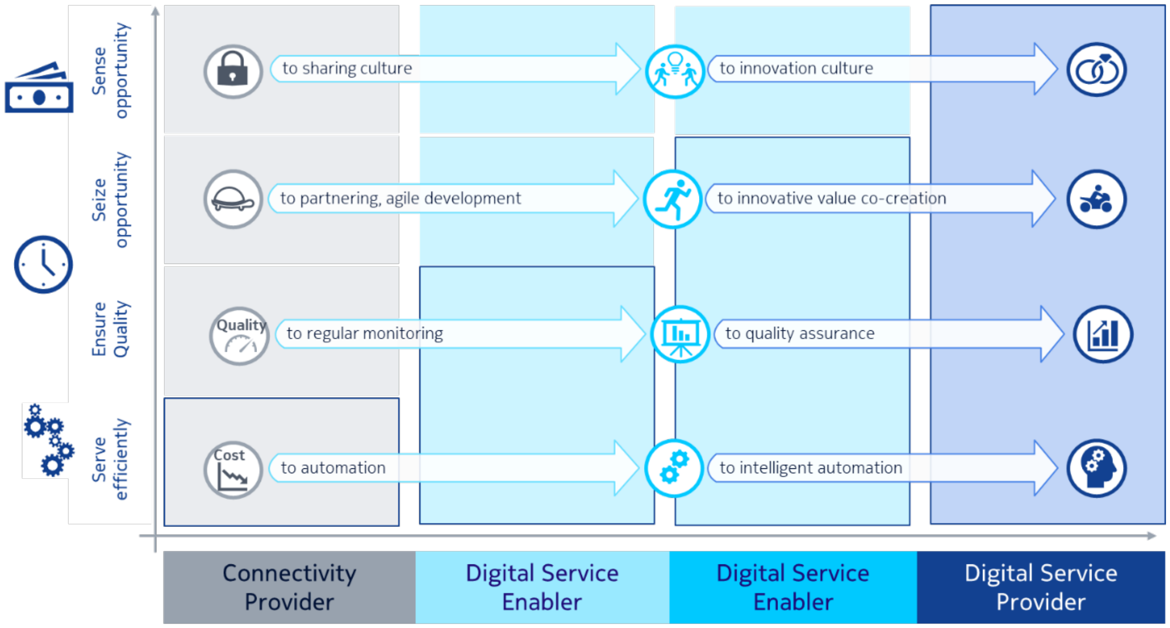
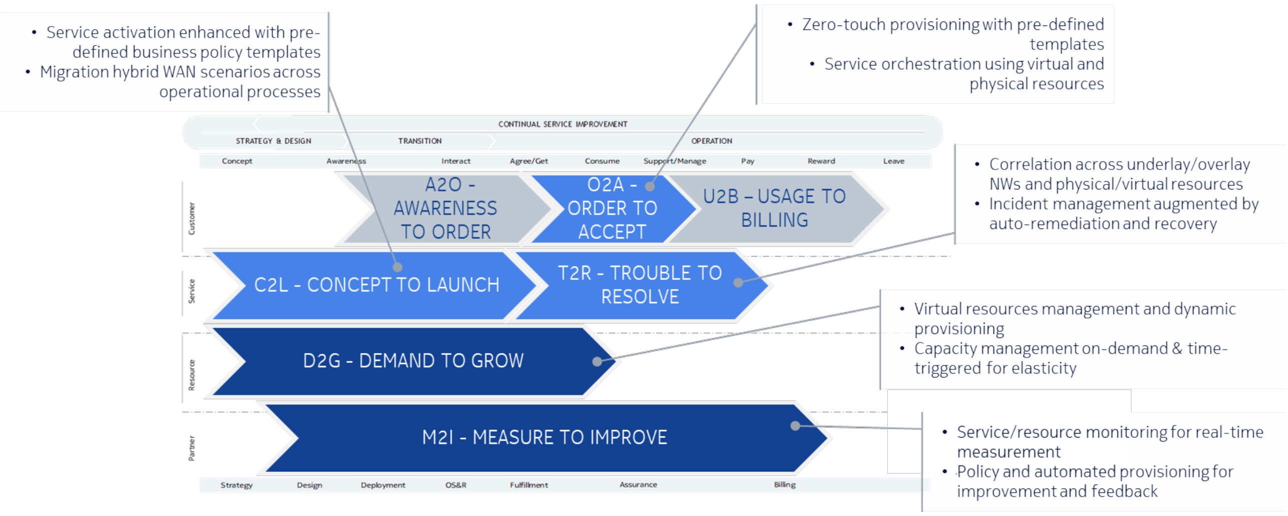


Figure 9 - Evolution requires operating model transformation

Telekom Austria identified the trend shifting towards digitalization and a fourth industrial revolution. As a result, Telkom Austria decided to not just stay as a “bit pipe” or “infrastructure” provider but to become “digitization enabler” (Annual Report 2016, 2019). The company decided to expand its portfolio into cloud and other ICT solutions. From 2016 to 2018, Telekom Austria established a “Digital Transformation Center of Excellence” (Combined Annual Report, 2018, 2018) to focus not only on process automation but also on marketing automation allowing target and successful communication to its customers by leveraging big data, analytics and artificial intelligence.



- Service activation enhanced with pre-defined business policy templates
- Migration hybrid WAN scenarios across operational processes

- Zero-touch provisioning with pre-defined templates
- Service orchestration using virtual and physical resources

- Correlation across underlay/overlay NWs and physical/virtual resources
- Incident management augmented by auto-remediation and recovery

- Virtual resources management and dynamic provisioning
- Capacity management on-demand & time-triggered for elasticity

- Service/resource monitoring for real-time measurement
- Policy and automated provisioning for improvement and feedback

Figure 10 - Impact across operations lifecycle value fabrics

5. Application (domain) Case Studies

This section is intended to make the content presented in the paper so far more tangible.

Table 4 shows application domains for different industry segments together with requirements that are specific for this segment / application. Three of them are described in more detail later.

Table 4 - Application domains by industry segment

Application domain	Main levers for Operators in the application domain[4]	Specific requirements / opportunities
eHealth	Connectivity to access points	Clinic connectivity and edge cloud for near real time/high data volume clinic appliances
Electric Utilities	(Small) generation control (solar, wind, etc.) Smart meters Network control (switches, compensation, synchronization)	Edge cloud for short latency
Gaming	Connectivity to access points, edge processing	Low latency, high bandwidth demands.

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[4] The intention is to reflect the anchor points of possible application scenarios here from which a business model can be developed.

Cities	Connectivity to smart meters, IoT devices of all sorts (sensors, actors)	
Ports	Connectivity to smart meters, IoT devices of all sorts (sensors, actors)	Edge cloud for short latency (autonomous vehicles)
Mining	Connectivity to mine, limited use within mine (assuming above ground mine)	Edge cloud for short latency (autonomous vehicles)
Manufacturing	Connectivity to plant, connection to access points within plant	Edge cloud for short latency (robot control, autonomic vehicles)
Rail	Connectivity to rolling material, sensors and actors at track (gates)	High reliability
Public Safety	Connectivity to sensors and actors	Edge cloud for short latency (where required / applicable)
Logistics	Connectivity to access points	Edge cloud for short latency (autonomous vehicles)
Agriculture	Connectivity to access points	Potential for edge cloud, wireless coverage within agriculture
Automotive	Connectivity to access points	Mainly mobile domain

5.1. Application Domain “eHealth”

eHealth utilizes the operator’s existing end user relationship and rich local infrastructure.

This application domain can be represented by a wide range of different individual applications, such as:

- **Fall detection and alerting**
  Fall detection and alerting can be implemented by a wearable device (e.g., wristband or watch) having the required sensors to identify falls and / or[5] video monitoring with corresponding video processing and recognition of anomalies (falls).
  Sensor (e.g., smart watch) based approaches can be easily achieved just using the data connectivity provided by the operator.
  Video monitoring based approaches can benefit heavily by the operator’s capability to easily provide computing capacity at the far edge[6] to process the video and potentially also make use of local call center utilities for further investigation if the automated video analysis suspects a call (e.g., calling the supposed fall victim or validating the call by online video observation – which likely requires prior approval by the client). Keeping video traffic very local in these cases will significantly improve the efficiency of the bandwidth use.
- **Emergency call feature**
  Emergency call feature, is commonly implemented by a wearable device with a button to be pressed in case of an emergency that immediately triggers an emergency call.
  Operators can support this feature utilizing a local call center. If that is done in conjunction with optional video monitoring this helps keeping video traffic local and thus efficient.

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[5] Fall detection can either be done by either of the two possibilities outlined or it can be done using both means simultaneously therewith achieving higher quality of the detection and less restrictions in the application.
[6] Far edge is the part of the edge far from the core network, i.e., close to the subscriber of the services.

- **Health signal monitoring**
  Health signal monitoring (e.g., heartbeat, ECG, etc.) with identification of anomalies and alerting. Operators can support this feature with computing power at the network edge, therewith significantly reducing the required network traffic by just sending information on anomalies long distance.

Given the specific expertise required for these applications and the potential consequences in case of wrong decisions taken, BM 4 is unlikely to be appropriate for this application domain. The other three business model blueprints are all applicable candidates with the value added by the operator increasing with higher BMs.

5.2. Application Domain "Electric Utilities"

Electric utilities have extensive networks coexisting across the territory of cable networks with similar characteristics (higher density in urban areas, simpler capabilities in rural areas).

This application domain can be represented by a wide range of different individual applications, such as:

- **Remote monitoring and control of distributed generation points**
  As electric grids become more diverse with generation activities occurring across their footprint, e.g., wind farms and down to individual residents with solar cell arrays, monitoring the condition of these extensions of the electrical grid becomes more complex and distributed over an ever increasing number of physical locations.
  Keeping the electrical grid stable in this environment will require tight control of the entity managing the power network over all of the generating entities with a short reaction time to enable continuous balancing of power production and demand.
  The power generating entities can as well be monitored remotely by drones piloted by experts in a metro utility office. Cable operators utilizing current telecommunication technologies to achieve fixed wireless access (FWA) can support the latency requirements for remote piloting and the bandwidth requirements for transmitting high resolution video back to the pilots. This can also be used in a weather emergency[7] or other outage situations to evaluate a situation more safely than by sending field workers in close.
  Operators can support this application by providing tailored communication capabilities and also computing resources at the far edge[6] to keep latencies low and avoid high volumes of data being sent large distance.
- **Smart metering**
  Dynamic rate shaping is becoming critical in localities where power consumption is stressing available generation or where continuing full power operations during unsafe periods (fire danger) is being avoided. Electricity consumers can get more detailed information on their usage and implement measures to save money. Utilities can obtain more granular detail about the energy consumption within their business area.
  In conjunction with remote control of generating entities this enables further improved control of the network.
  Operators can support this application by providing communication to the smart meters. The combination with the control of power generating entities leads to the option of providing edge

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[7] Some kinds of weather emergency may not be appropriate for this approach as flying drones may not be possible under certain circumstances.

computing resources to deal with load balancing in the vicinity (e.g., collocated with OLTs – see Figure 11), improving communication efficiency as well as power network resiliency.

Figure 11 - Substation / OLT area overlap[8]

All business model blueprints are applicable to this application domain with the sweet spot likely being BM 3. BM 4 requires a significant amount of application domain-specific knowledge and may thus be difficult to realize in a full-fledged manner, [7]. Parts of the information flows that are more generic may be applicable to a BM 4-like business model, e.g., providing information to power utility customers about their consumption (or production in case of customers that are also possessing generating capabilities) profile via web- or app-based GUIs.

5.3. Application Domain "Gaming"

Over nearly five decades gaming has evolved from a single user experience sitting in front of his console (recall "Pong" anyone?) towards massive multiplayer online gaming. This was supported by an evolution where earlier gaming had all the components required for gaming concentrated in the console to current gaming approaches that necessitate and enable additional architectures.

Content distribution architectures (video, audio) can relatively easily be optimized by utilizing content servers that are reasonably close to the end user in combination with the introduction of buffers to guard against fluctuations in available bandwidth this is not possible for gaming with dynamically created content and low latency requirements.

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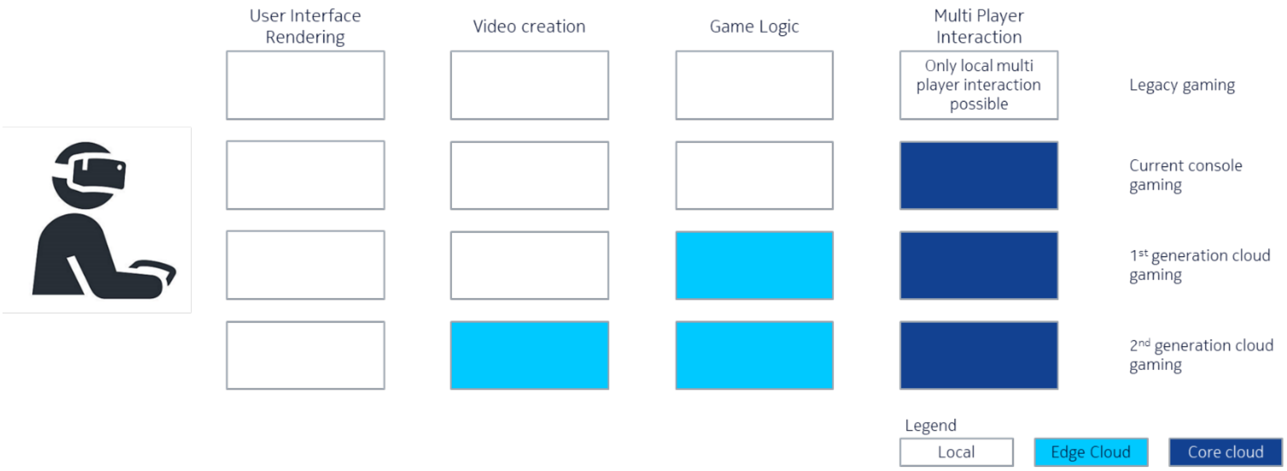
[8] Symbolic picture: only one substation and OLT area shown to simplify the depiction.



	User Interface Rendering	Video creation	Game Logic	Multi Player Interaction
Legacy gaming	☐	☐	☐	Only local multi player interaction possible
Current console gaming	☐	☐	☐	■
1st generation cloud gaming	☐	☐	🟦	■
2nd generation cloud gaming	☐	🟦	🟦	■

Legend
☐ Local
🟦 Edge Cloud
■ Core cloud

Figure 12 - Gaming architectures

Figure 12 shows a snapshot on several gaming architectures.

- **Legacy gaming**
  The legacy gaming architecture has all required components integrated in the console[9]. Multi-player interaction is only possible to participants on the same LAN ("LAN party") with the different consoles directly interconnected.
- **Current console gaming**
  Current console gaming typically supports multi-player gaming over the Internet where the global game coordination is handled by a central server with all the interaction and low latency processing being handled locally.
- **1st generation cloud gaming**
  Current console gaming requires massive processing and rendering power at the local hardware level. 1st generation cloud gaming helps get rid of this requirement by moving significant parts of the processing to the cloud. This approach requires very low latency network connectivity to avoid putting the "cloud gamer" in disadvantage relative to gamers playing the same game using a current console gaming architecture.
  In this architecture the rendering commands are created in the cloud while the rendering of the video displayed to the user is performed locally from the rendering commands created in the cloud, limiting the amount of data to be transmitted.
- **2nd generation cloud gaming**
  2nd generation cloud gaming reduces the task of the local equipment to providing the pure user interface to the gamer. The complete gaming logic and video rendering are happening in the cloud in this architecture. This reduces the performance requirements for the user equipment massively while increasing the demands on the network connectivity (especially increasing the bandwidth demands due to the need to transmit the fully rendered video, while keeping the low latency requirements).

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[9] The term "console" as used in this section includes classical gaming consoles (like PlayStation®, xBox®, Switch®) but also Windows® or Apple® PCs as well as smart phones running corresponding gaming applications or platforms.

With regard to applicable business model blueprints, gaming will in most cases require a certain degree of partnerships as the majority of games are published by a few big gaming houses / hosted on a few gaming platforms. These are also likely to provide the core cloud capabilities to enable truly global gaming capabilities. The low latency / high bandwidth requirements are better satisfied by the cable operator being able to run these components of the architecture on an edge cloud that is close to the user, therewith also minimizing the network impact of the (video) streams to be transmitted.

A close to optimal technical solution to the requirements of gaming is the cooperation of an operator with a (globally acting) gaming platform; ensuring processing intensive but latency sensitive computing resources in the far edge[6], close to the subscriber while utilizing the game provider to enable interaction with a global community of gamers.

6. Conclusions

As cable operators invest in digitizing their operations and adopting more FX architectures, more and more of these business model blueprints will be available to them. We expect operators to develop a blend of business models to retain their legacy connectivity business revenues while selectively claiming new revenues in domains and verticals they feel best suited for.

BM 1 “bit pipe provider” is legacy business for each operator and will likely be required as ongoing service for residential customers.

BM 4 “solution provider,” as the other extreme, requires a significant degree of domain-specific knowledge. Thus, it is unlikely that any operator will be able or willing to go into this level of detail for a lot of different domains – and if it does it would likely require handling these different domains at the application level by teams that have little commonality. This will start to resemble internal partnering, comparable in execution to providing the service with an external partner.

BM 2 “infrastructure provider” and BM 3 “platform provider” are somewhere in between these two ends of the spectrum, where we see high likelihood that BM 2 “infrastructure provider” will be offered to verticals in a similar way as BM 1 “bit pipe provider” is offered to residential subscribers while providing BM 3 “platform provider” for a selected set of domains that has a high likelihood of multiple co-operations with different application provider verticals.

It is also possible (as outlined in Section 5.2) that within an application domain different business model blueprints are applied to different aspects of the problem statement, i.e., leaving the domains that are highly demanding from an application domain perspective to a specialist (using any of BM 1 to BM 3) while providing the complete solution (applying BM 4) for the less demanding components.

Clearly all of these business model blueprints benefit from highly evolved, digitalized operating models with a high degree of automation. Further evolution in this direction that makes the “higher” business model blueprints feasible will simultaneously make the “lower” business model blueprints typically more efficient or have at least no negative impact on them. It is likely that over time cable operators will use two or more of the identified business model blueprints as a basis for their value delivery.

As soon as several applications having different performance requirements (e.g., latency vs. bandwidth vs. reliability) are present in the same network, this creates additional requirements to be able to simultaneously and efficiently satisfy these requirements. This requirement points to another technological solution – slicing – whose technical, operational and economic properties are well addressed in [3].

The four business model blueprints, BM1 through BM4, provide cable operators with a set of blueprints that can be used as foundation for designing their operating model for the emerging diverse needs of enterprises.

7. Abbreviations and Definitions

7.1. Abbreviations

5G	fifth generation [mobile telecommunications technology]
API	application programming interface
BM	business model (blueprint)
DC	data center
DOCSIS	Data-Over-Cable Service Interface Specifications
ECG	electrocardiogram
FTE	full-time equivalent
FWA	fixed wireless access
FX	Future X
GUI	graphical user interface
IaaS	infrastructure as a service
ICT	information and communication technology
IoT	Internet of Things
IP	Internet Protocol
ISBE	International Society of Broadband Experts
IT	information technology
LAN	local area network
MSO	multiple system operator
OLT	optical line termination
OT	operational technology
OTT	over the top
PaaS	platform as a service
OS	operating system
PON	passive optical network
SCADA	supervisory control and data acquisition
SCTE	Society of Cable Telecommunications Engineers
SDN	software defined network
VR	virtual reality
XaaS	anything as a service
XGS-PON	10 gigabits per second symmetrical PON

7.2. Definitions

operational technology	Hardware and software that detects or causes a change, through the direct monitoring and/or control of industrial equipment, assets, processes and events.

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