Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of:	)	
	)	
Authorizing Permissive Use of the "Next Generation" Broadcast Television Standard	)	GN Docket No. 16-142
	)	
	)	

<u>Comments of</u>

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SUMMARY

The authors submit these comments in response to the Commission's *Notice of Proposed Rulemaking* ("NPRM") concerning the authorization of television broadcasters to use the "Next Generation" broadcast television (Next Gen TV) transmission standard ATSC 3.0.

In a first submission on May 9th 2017, we presented the study "*Quantifying LDM Mobile TV Service Coverage Spillover into Fixed Rooftop Reception: Increased Coverage Overlap Between U.S. Service Areas"*, later presented at the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (IEEE BMSB) on Cagliari, Italy in June 7, 2017. In that study we argued that, as ATSC 3.0 will provide the ability to send simultaneous Physical Layer Pipes (PLPs) at a variety of signal robustness levels, ATSC 3.0 is expected to be used to deliver service targeted to mobile receivers as well as service to fixed rooftop antennas using Scalable Hierarchical Video Coding (SHVC) and Layered Division Multiplexing (LDM). In such a scenario, TV signals will be readily receivable by rooftop antennas over a much larger area than today's 15 dB "DTV-equivalent" coverage contour and thus this will lead to substantially increased coverage overlap between same-network local TV station affiliates. We conservatively estimate that as much as 75% of the population would have access to at least one redundant network affiliate, and 60% will have access to two affiliates or more for all four major networks. This would have potential implications for program choice, MVPD carriage and retransmission consent negotiations.

In the current further NPRM, the Commission seeks comment on its tentative conclusion that local simulcasting should not change the significantly viewed status of a Next Gen TV station. As OTA coverage by itself does not tell if an increase in coverage overlap between same-network affiliates will create issues to the existing MVPD carriage regime but only when a TV station gets classified as significantly viewed. Thus, it is important to understand if mere increase in OTA coverage makes it more likely for a TV station to be classified as significantly viewed. We present recent results (attached below) where we build a model which predicts how an increase in coverage overlap resulting from LDM and SHVC would in fact increase the number of counties where out-of-market TV stations become significantly viewed. We calculate current county-based coverage at ATSC 1.0's 15 dB contour that we use in addition to the publicly available list of existing significantly viewed TV Stations to train a *random forests* binary classification model. For an appropriate choice of classification cutoff, the classification model predicts a TV station's SV status with a true positive rate (TPR) of 96% and a false positive rate (FPR) of 5% for the case of today's ATSC 1.0. We then use that model in combination with a projection of increased coverage under ATSC~3.0 to estimate the number of additional SV {county, TV station} pairs. Assuming the ATSC~3.0 broadcaster chooses to transmit a LDM upper layer for mobile devices encoded for a CNR reception threshold of 2 dB (equivalent in bitrate to one full-HD 1080p program), the classification model predicts that increased coverage by rooftop receivers will lead to an increase in new significantly viewed {county, TV station} pairs of 100% or more. These results suggest that as ATSC~3.0 adoption increases, the use of

LDM and SHVC can have a substantial impact on significantly viewed status, and thus on MVPD carriage.

The NPRM reasonably concludes that significantly viewed status should be frozen, with respect to any change in coverage that might result from the transfer of a station's ATSC 1.0 signal to a different broadcaster for simulcasting. It is silent, however, on the likely increase in significantly viewed stations that will result as ATSC 3.0 transmission and adoption by viewers proceeds. The longer the freeze continues, and the greater the adoption of ATSC 3.0 reception by households, the more the discrepancy will grow between the frozen classification status and actual significantly viewed stations. As this discrepancy grows, it will become increasingly disruptive to recognize the new reality that will emerge from ATSC~3.0 adoption.

As previously noted we agree that significantly viewed status should not change as the result of Next Gen TV stations moving their 1.0 simulcast channel. On the other hand, we propose that the Commission continue to update its list of SV stations based on changes in viewing that result from the deployment and adoption of ATSC~3.0 transmission. This will allow the marketplace to gradually adjust to the changes in coverage and viewing habits that we predict when ATSC 3.0 becomes widespread. Maintaining the status quo with respect to eligibility for significantly viewed carriage may avoid complications or disruptions to the MVPD carriage regime in the short term. However, the R&O and FNPRM are silent as to how long the simulcasting period will last, or how exactly the simulcasting period will end, e.g. at a nationwide level or via a market-by-market approach. The longer the potential freeze on significantly viewed status of 3.0 signals, the larger the potential disparity between the reality and the

legality of significantly viewed status. Therefore, a freeze which does not allow for adjustment of significantly viewed status for neither 1.0 nor 3.0 signals may ease the burden in the short term only to create a bigger issue in the long run. By allowing significantly viewed classification to change as ATSC~3.0 coverage expands, we can avoid creating a future disruption when the legal and the real are reconciled.

Significantly viewed status has key ramifications for TV stations and MVPDs: it allows stations to compel out-of-market satellite carriage ("local-in-local"); it reduces the copyright payments that MVPD providers might otherwise be obliged to pay, affecting carriage decisions; and it provides an exemption from network non-duplication or syndicated exclusivity rights. Foreclosing Next Gen TV stations from enjoying the significant benefits that come from designation as significantly viewed through the proposed freeze on significantly viewed designations, may actually serve to delay Next Gen TV expansion.

LDM and SHVC Mobile TV Coverage Spillover into Fixed Rooftop Reception and MVPD Retransmission Consent in the U.S.

Rolando Bettancourt and Marvin A. Sirbu

***Abstract*—ATSC 3.0 is likely to be used to deliver service targeted to mobile receivers as well as service to traditional fixed rooftop antennas. By jointly using Layered Division Multiplexing (LDM) and Scalable Hierarchical Video Coding (SHVC), a Physical Layer Pipe (PLP) with robust coded modulation equivalent to 0–2 dB of carrier-to-noise ratio (CNR) —i.e. optimized for mobile reception in an area comparable to a TV station's current coverage— will be decoded by rooftop antenna receivers over a much larger area than today's 15 dB ATSC 1.0 coverage contours. Although ATSC 3.0's LDM+SHVC has the potential to greatly improve TV reception, these larger coverage areas will also give rise to increased overlap between same-network local TV station affiliates. We calculate the potential increased coverage overlap among affiliates of the four largest over-the-air TV content distribution networks (ABC, CBS, NBC and Fox) over the Continental U.S. and we conservatively estimate that as much as 75% of the population will have access to at least one redundant network affiliate, and 60% will have access to two affiliates or more for all four major networks. In addition, when multiple independently-owned affiliates of the same content network overlap the subscriber footprint of an Multichannel Video Program Distributor (MVPD), the MVPD can pit these affiliates against each other in bargaining over lower retransmission consent fees. Under U.S. Federal Communications Commission (FCC) rules, this can only happen if the out-of-market TV station has been classified by the FCC as *significantly viewed* (SV), on a per county basis. Thus, we analyze if an increase in coverage overlap resulting from LDM+SHVC would in fact increase the number of counties where out-of-market TV stations become SV, potentially leading to new redundant affiliates carried by an MVPD. We calculate current ATSC 1.0 15 dB county-based coverage that we use in addition to the publicly available list of existing significantly viewed TV Stations to train a Random Forests binary classifier. For an appropriate choice of classification cutoff, the classifier predicts a TV station's SV status with a true positive rate of XX% and a false positive rate of 5% in the training 15 dB dataset. With a LDM upper layer encoded for a CNR reception threshold of 2 dB —equivalent in bitrate to one full-HD 1080p program—, the model predicts an increase in new SV county/TV station pairs of around a 100%. This suggest that LDM+SHVC can have a substantial MVPD carriage effect and thus should be carefully considered by both industry players and regulators.**

***Index Terms*—ATSC 3.0, Mobile TV, Layered Division Multiplexing, Scalable Hierarchical Video Coding, Predicted Coverage, Retransmission Consent, Binary Classification, Random Forests, Machine Learning.**

I. INTRODUCTION

There have been numerous suggestions that ATSC 3.0 will be used to provide service targeted to mobile receivers as part of a broadcaster's overall next-generation TV strategy [1]–[3]. In the past, the main technical barrier to successfully deploying Mobile TV has been the 20–30 dB of additional link budget required in comparison to fixed rooftop reception [4], [5]. To address this, ATSC 3.0 includes Layered Division Multiplexing (LDM) as part of its physical (PHY) layer, which is a more efficient multiplexing scheme than FDM/TDM when transmitting multiple program streams with dissimilar bitrates and robustness levels —e.g. fixed and mobile [4], [6]. Moreover, unlike ATSC 1.0, the new ATSC 3.0 provides the ability to send simultaneous PLPs at a variety of signal robustness levels defined via different modulation and coding schemes (MCS) [1], so broadcasters could, from the same broadcast tower, serve both fixed and mobile receivers [4]. In this regard, what seems to be the most cost-effective strategy for deploying Mobile TV is to use LDM in conjunction with Scalable Hierarchical Video Coding (SHVC) [2], [7]. Here, a downscaled HD resolution version is transmitted in a PLP targeted for mobile receivers, while a second PLP targeted for rooftop receivers contains the additional source bits required to realize the original UHD version: fewer bits are required in total, and the redundancy of providing two complete program streams for both mobile and fixed reception is avoided. As a consequence, with LDM+SHVC, a Physical Layer Pipe (PLP) with robust coding optimized for reception by mobile receivers in an area comparable to a TV station's current ATSC 1.0 coverage will be readily decodable by TV households using rooftop antennas, spilling over a much larger area than today's 15 dB coverage areas [4], [6].

Nevertheless, using these mobile-optimized ATSC 3.0 planning parameters in the United States (U.S.) will also frequently result in new/additional coverage overlap between same-network TV station affiliates, which can have implications for program choice, carriage and retransmission consent with Multichannel Video Programming Distributors (MVPDs). In the U.S., over-the-air (OTA) broadcast TV is distributed across a complex structure of 210 *designated market areas* (DMA), and within each DMA, the majority of its local TV stations are affiliated with a national content distribution network —e.g. ABC, CBS, The CW, NBC, Fox, Telemundo [8]. For local TV affiliates of the same network, they serve different local metropolitan areas, only differing between them in the provision of tailored local news and other forms of local programming; most of their popular programming comes from their parent network, and is thus the same. Due to station

ownership limitations [9], these neighboring local TV affiliates typically don't share the same owners, and therefore they may compete where coverage already overlaps. This competition takes place in terms of viewership, advertising revenues and retransmission consent fees—in varying degrees—, being the MVPD carriage issue the more tangible short-term effect. In the U.S., less than 15–20% of TV viewers receive their content directly over the air, while the rest receives the content via some type of MVPD. Therefore, the relationship between free OTA TV broadcasters and MVPDs is pivotal.

In the U.S., TV broadcasters have been able to demand increasingly higher retransmission consent fees from MVPDs, which has created a number of disputes at the private and public level, specially because of events of rough negotiation disputes where local TV stations end up pulling out their programming of the MVPD they are negotiating with due to lack of agreement, which are known as *blackouts*. The leverage that TV broadcasters enjoy when negotiating with MVPDs comes from the fact that (i) the content they distribute is rather unique, popular, and cannot be easily substituted, and that (ii) local TV stations are the exclusive distributor of this content in their local TV markets.[1] With an hypothetical increase in coverage overlap due to ATSC 3.0's LDM+SHVC, TV stations effectively lose their OTA exclusivity. However, they do not automatically lose exclusitivy at the MVPD level as U.S. MVPD carriage is not intended to necessarily replicate OTA coverage. Under the rules of the U.S. Federal Communications Commission (FCC), only TV stations that exceed a certain minimum threshold of significant OTA viewership and circulation, i.e. are *significantly viewed* (SV), are allowed to enter in retransmission consent negotiations outside of their local DMAs (see Section II-C).

In this paper we first quantify the extent of the potential increase in OTA coverage overlaps between same-network affiliates, and then we analyze if there is evidence to support that such LDM+SHVC could actually affect local TV stations' ability to extract retransmission consent fees by increasing the overall number of U.S. counties where TV stations become a SV out-of-market network affiliate. In general, we restrict our attention to those local TV stations that are affiliated with the largest four U.S. national broadcast networks: ABC, CBS, NBC and Fox. To determine the potential increase in OTA coverage overlap of providing simultaneous service to both mobile and fixed receivers, we choose a representative ATSC 3.0 SHVC+LDM configuration and we assume that all TV stations in the U.S. will adopt it. Particularly, we assume TV stations maintain their assigned transmit power as proposed in [3]. Then, using the FCC's TVStudy interference analysis software [10] we calculate in terms of area and population served (a) today's existing coverage overlap with ATSC 1.0, i.e. a CNR reception threshold of 15 dB; and (b) the hypothetical coverage overlap that would result with ATSC 3.0's LDM-SHVC with a CNR reception threshold of 2 dB.

To predict the potential increase in SV out-of-market TV stations due to increased OTA coverage overlap, we estimate the statistical relationship between TV stations' current ATSC 1.0 per-county population coverage and their current out-of-DMA SV status. For this, we train a *Random Forests* classification model [11], considering a TV station's county coverage as one of the possible multiple independent variables (predictors) of SV status, and its actual SV status as the (binary) dependent variable of the model. With the obtained (non-parametric) relationship, we then input the resulting ATSC 3.0 LDM-SHVC 2 dB coverage to, conservatively, forecast the number of new network affiliate/county pairs that would eventually achieve SV status, all else equal.

The rest of the paper is structured as follows. Section II focuses on the technology and regulatory background of this paper. Section III describes input data sources and computation methodology. Section IV defines the scenario here considered and compares the OTA coverage overlaps obtained with ATSC 1.0 and ATSC 3.0's LDM-SHVC. Section V discusses the retransmission consent implications of additional same-network overlap while Section VI forecast the potential increase of SV status. Section VII provides our conclusions.

II. BACKGROUND

In this section we describe the most relevant aspects of (a) the use of LDM and SHVC to provide Mobile TV service, and (b) the industrial structure of the U.S. TV industry, the roles of MVPDs, and the associated FCC regulatory framework.

A. LDM and SHVC for Mobile TV

As noted above, a two-layer LDM+SHVC scheme has been proposed to facilitate the delivery of Mobile TV services [2], [7]. At the source coding level, two SHVC layers are created from an original high-quality video source: a *base layer* (BL), optimized for mobile device displays, and an *enhancement layer* (EL), optimized for fixed rooftop reception and large-screen household TV sets. The BL corresponds to a down-scaled lower-quality version of the original video source, while the EL, when received together with the BL, provides the incremental bits to bring the BL to the original video quality [7]. SHVC reduces the total bitrate requirement compared to simulcasting in two different qualities [12]. Examples of these scalable video qualities are resolution are high-definition to 4K ultra-high-definition (UHD), dynamic range (8-bit to 10-bit depth) and frame rate (e.g. 30 fps to 60 fps) [12].

At the transmission channel level, ATSC 3.0 incorporates the use of LDM for the simultaneous non-orthogonal transmission of the BL and EL with unequal error protection (UEP) [1]. The LDM *upper layer* (UL), which is intended for transmitting the BL, is encoded with a robust MCS so that mobile receivers can decode it at low SNR thresholds. The LDM *lower layer* (LL), which is intended for household reception via rooftop antennas, is encoded with a high-capacity MCS to take advantage of household's better reception conditions. It

[1] The issue of wether MVPDs are unwilling to pay fair market prices or TV broadcasters are demanding excesive retrans fees is still a very contentious regulatory debate [ref].

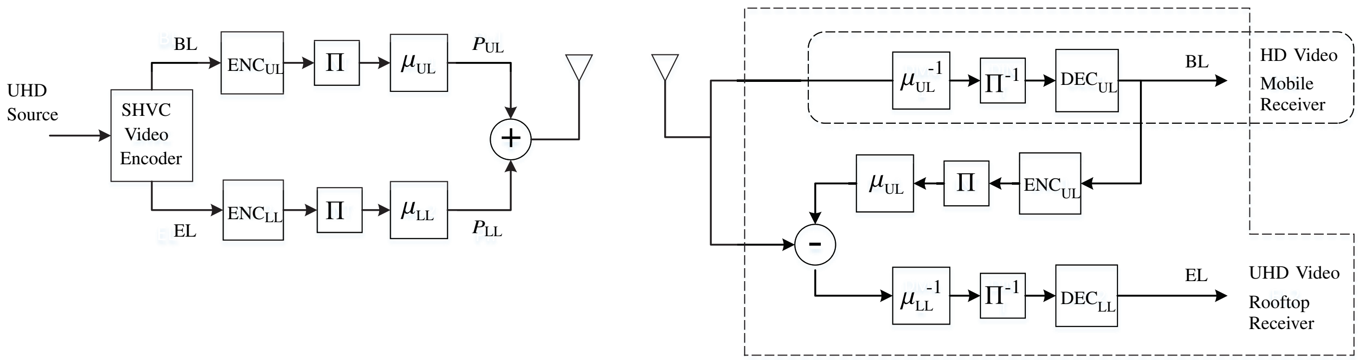


Figure 1. Source and channel coding of a SHVC over LDM video transmission, as shown in several ATSC 3.0 industry presentations. The BL and EL are encoded (ENC), passed though an interleaver Π and symbol-mapped $\mu\{\cdot\}$ at different SNR robustness levels. Then, they are combined at power levels P_{UL} and P_{LL}.

has been shown that the gain of LDM over time-division and frequency-division multiplexing (TDM/FDM) increases with the difference in the required SNR levels of the two layers [5], as indeed occurs with the simultaneous in-band provision of fixed and mobile services.

With the proposed ATSC 3.0 LDM transmitter, the output signal is the sum of the UL and LL OFDM carriers [4], [13]. The power levels at which both layers are added, P_{UL} and P_{LL}, is controlled by the so-called *injection level* (IL) ρ, which represent the difference (in dB) between the power allocated to the UL vs the LL, i.e. $\rho = 10\log_{10}(P_{\mathrm{UL}}/P_{\mathrm{LL}})$. Hence,

$$P_{\mathrm{UL}} = \frac{1}{1+10^{\rho/10}}\cdot P_0$$
$$P_{\mathrm{LL}} = \frac{10^{\rho/10}}{1+10^{\rho/10}}\cdot P_0 \quad (1)$$

where P_0 is the total (carrier) transmit power, i.e. $P_{\mathrm{UL}}+P_{\mathrm{LL}} = P_0$. In this way, mobile receivers see the LL as additional noise, while fixed receivers are able to perfectly decode and cancel the UL layer before decoding the LL due to the large signal-to-noise ratio (SNR) differential [5]. Because of this, the LDM transmission scheme can be decomposed into two parallel channels with noise N_0B and SNR levels given by

$$\gamma_{\mathrm{UL}} = \frac{P_{\mathrm{UL}}}{P_{\mathrm{LL}}+N_0B}$$
$$\gamma_{\mathrm{LL}} = \frac{P_{\mathrm{LL}}}{N_0B} \quad (2)$$

Similarly, taking γ_{UL} and γ_{LL} as the required minimum SNR level for the MCSs at the UL and LL respectively, the minimum CNR planning levels required for the UL and LL streams to be decoded correctly are given by

$$\mathrm{CNR}_{\mathrm{UL}} = \gamma_{\mathrm{UL}} + 10\log_{10}\left[1+10^{\rho/10}+10^{(\rho+\gamma_{\mathrm{UL}})/10}\right]$$
$$\mathrm{CNR}_{\mathrm{LL}} = \gamma_{\mathrm{LL}} + 10\log_{10}\left[1+10^{-\rho/10}\right] \quad (3)$$

Recent examples in the literature have shown that with their existing 6 MHz channel, ATSC 3.0 broadcasters using LDM can provide mobile service coverage fairly close to today's ATSC 1.0 15 dB coverage contour, and at the same time provide enhanced quality fixed services at that 15 dB level [4], [6]. However, it has also been noted that, because of its more robust coding, the LDM UL alone can be received by fixed rooftop receivers at distances far beyond today's 15 dB coverage contour [4], [6], which is the phenomenon we analyze in this paper.

B. U.S. Broadcast TV Marketplace

By late April 2017 there were 2074 Full-Power or Class-A local television stations in the U.S., operating either in the Low-VHF, High-VHF or UHF bands. Among them, more than 80% are commercial television stations that are financed primarily via advertising [8]. U.S. local TV stations are grouped into a structure of of 210 designated market areas (DMAs), which are are groups of counties where people see roughly the same OTA TV options. It is important to note that DMAs are the basis of where local television viewing is measured by The Nielsen Company.[2]

Network affiliate TV stations bundle a limited amount of locally produced "local" programming, including news, weather, public affairs, etc., with network programming acquired from national broadcast networks with which they are affiliated (e.g. ABC, CBS, NBC, Fox)[3]. Although local TV stations provide their content to households directly through free over-the-air service, households can also receive local TV stations through retransmission by MVPDs such as cable, telco and satellite operators. In general, the flow of content in the TV industry starts by content producers (e.g. Sony, Disney, others) sell the

[2]For a detailed description of the structure of Nielsen's DMAs, see http://www.nielsen.com/intl-campaigns/us/dma-maps.html.

[3]TV stations may acquire other non-local programming, known as syndicated programming that can include game shows, reruns and, sometimes, some original programming. See [8].

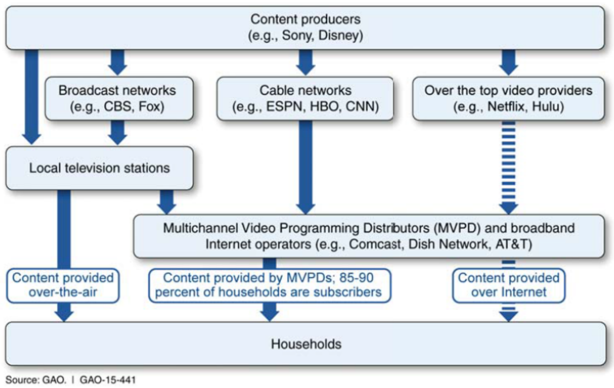


Figure 2. Broadcasting Industry Participants and Flow of Television Content. Figure taken from [14]

rights to distribute their content to broadcast networks (e.g. ABC, CBS, NBC, Fox), cable networks (e.g. HBO, Cinemax) and over-the-top (OTT) distributors (e.g. Netflix, Amazon Video, Hulu). MVPDs aquire the right to retransmit the content of both cable networks and OTA broadcast networks, and around 80–85% of households are subscribed to an MVPD. See Fig. 2.

As MVPDs compete with local TV stations for both viewers' attention and advertisers, the U.S. Congress mandates MVPD carriage as a way to ensure the economic viability of free OTA television. Local TV stations may elect MVPD carriage under either must-carry or retransmission consent [8]. Under must-carry, local TV stations can demand carriage of their primary program channel by MVPDs within their DMA, but without compensation from the MVPD. Alternatively, under retransmission consent, broadcast stations may demand some form of consideration in return for providing their consent to an MVPD to carry their signal. Today, TV stations typically receive a fixed negotiated per-subscriber fee in exchange for their content, and virtually all commercial TV stations are able to extract positive revenue from MVPDs[4]. For a complete picture of how monetary payments flow throughout the TV industry, fees and advertising revenues, see Fig. 3.

In general, the amount of programming and its video quality that each TV station can broadcast and the population they can reach over the air is subject to (a) the existing broadcast technology (e.g. ATSC 1.0) and (b) FCC rules that limit the maximum transmit power and the maximum transmit antenna height of broadcast facilities[5]. With respect to the assignment of TV spectrum licenses, this has followed a first-come first-served approach, where a TV license can be granted in any place as long as there exists an available frequency —i.e. does not cause harmful interference to incumbent TV stations. Now, whether a TV station wants to use its OTA bitrate to transmit, e.g., a single UHD program, or multiple sources of HD or SD programming, that will be up to each specific TV station/broadcaster, i.e. a business decision.

[4]Source: SNL Kagan, an offering of S&P Global Market Intelligence.

[5]See 47 CFR §73.622(f) for DTV maximum power and antenna heights.

C. MVPD Retransmission and SV Status

To define who can demand MVPD carriage and where, the FCC uses Nielsen's DMAs as the basic geographic unit. Defined by Nielsen Media Research, each DMA is composed of a group of counties, generally clustered around a major metropolitan area, where local TV stations within such DMA hold statistical viewership dominance compared to TV stations of neighboring DMAs [8], [15]. Network affiliated TV stations often receive exclusive rights from the network to distribute its programming within their DMA, which, as mentioned before, gives them substantial leverage when negotiating retransmission consent fees. Moreover, the network non-duplication rule requires MVPDs to delete duplicating programming in a community that falls within a TV station's *protected zone*[6] (although in practice, networks and their affiliates have expanded the exclusivity zone to include entire DMAs). Nonetheless, an exemption to this rule applies in the case of the so-called *significantly viewed* (SV) out-of-market TV stations. SV stations are TV stations that have a significant OTA viewership outside of their DMA [16], and the determination of SV is made on a county by county basis [17]. The specific SV minimum is at least a 3% share of total weekly viewing hours and a net weekly circulation[7] of 25% by at least one standard error. This measure is obtained from OTA reception only, excluding MVPD viewership. Although SV stations cannot demand must-carry outside of their DMAs, but existing regulations do allow them to negotiate retransmission consent fees with any MVPD whose footprint falls within any portion of a county for which a TV station has been declared SV [18]. MVPDs are not required by the FCC to delete duplicate network programming when it comes from SV stations, and in-market network affiliates cannot prevent an MVPD from carrying them [19]. As noted, MVPDs have little incentive to negotiate retransmission consent with non-SV, out-of-DMA network affiliates as they would be required to delete any programming duplicative of the in-DMA affiliate.

[6]See 47 CFR §76.92 Cable network non-duplication rules

[7]Weekly circulation referred to the number of households that viewed the station for 5 minutes or more during the entire week.

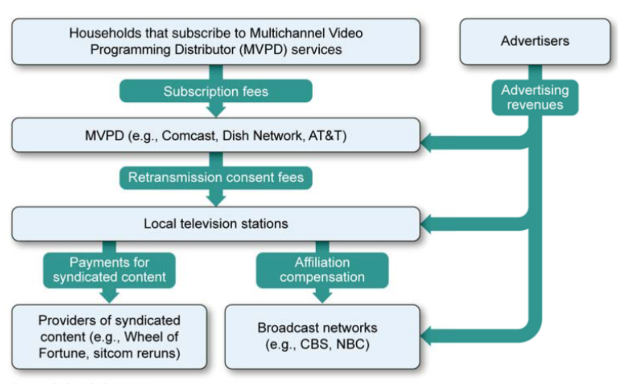


Figure 3. Flow of Money in the Broadcasting Industry. Figure taken from [14]

Regarding the DMA geographic structure itself, it is common to find mismatches between TV stations' coverage areas and their DMA areas. Some TV stations' coverage does not extend to their entire DMA, and/or their coverage area may spread across more than one DMA. Changing a TV stations' coverage area may affect how MVPDs whose footprint includes viewers of overlapping network affiliates determine which affiliate(s) to carry and how much to pay for the signal, or conversely, the ability of local broadcasters to extract retransmission consent payments.

III. Data Breakdown and Coverage Calculation

In this section we briefly summarize our data sources and revisit the FCC OET-69 methodology we use to calculate coverage and population served with TVStudy.

A. Data Sources

The FCC Media Bureau's Consolidated Database System (CDBS) is a public access relational database that contains, among other information, the engineering data of each TV station facility in the U.S. This data is comprised of a TV station's transmitter geographic location, transmit power, frequency of operation, antenna height and the transmit antenna's horizontal and vertical patterns. Each broadcasting facility is indexed with a *facility ID*, which is in turn associated to the *call sign* of the TV station it belongs (e.g. KDKA-TV, WTAE, WNBC, etc.). This information is used by TVStudy, in addition to topographic SRTM-3 data [20], to provide TV stations' coverage calculations over a 2 km by 2 km grid, which is delivered as a set of comma separated values (CSV) output files. We use MATLAB® for further analysis of these files.

In today's 210 DMA regions, every county in the U.S. is in a DMA. We obtain the relationship between U.S. county and DMA via data provided by S&P's SNL Kagan. This county by DMA report is updated annually, so we use the latest version available to us, which corresponds to the year 2016. In addition, we also use S&P's SNL Kagan to obtain for each DMA their complete list of TV stations and their corresponding network affiliations. To obtain each DMA's geographic boundary, we use MATLAB's mapping toolbox to perform the union operation of the polygons that represent each county. For each county, we use their respective cartographic boundary shapefiles with a resolution of 500k = 1:500,000 which are readily available at the U.S. Census Bureau website.

To obtain the data on TV stations' significantly viewed status, we use the official list of SV TV stations per county available from the FCC[8]. The SV list is a PDF file where TV stations are listed by state and by the county in which they are significantly viewed. This list was last modified in April 2016. To convert this information to a more manageable format, we use the extraction and data mining software SiMX TextConverter®, taking advantage of the structure of the file. So far, there is no publicly available tabulated version of this information.

[8]At http://www.fcc.gov/mb/ in accordance with 47 U.S.C. §340(c)(2)

B. TV Coverage Calculation Remarks

The FCC TVStudy software v2.2.4 implements the official FCC OET-69 directive for calculating coverage areas and population served for TV stations in the U.S. [21]. The OET-69 directive considers two different propagation models. A first model, called the "FCC Curves", is a statistical path loss model akin to the ITU-P.1546 recommendation, where path loss monotonically increases with respect to the distance to the transmitter. A second model, called the irregular-terrain Longley-Rice (ITM) model, can take into account clutter and terrain elevation characteristics [10], [21]. In practice, the "FCC curves" tend to be a coverage upper bound with respect to the ITM model.

The protected service area of a TV station is defined by the so-called *noise-limited contour*, which is delineated using the F(50, 90) curves —where reception is available for 50% of locations within the contour at least 90% of the time. The noise-limited contour bounds the area from the TV transmitter to the distance at which the field strength predicted by FCC curves falls to a minimum field, corresponding to today's ATSC 1.0 SNR level of 15 dB. To determine population served, the OET-69 method divides the area within this contour in 2 km by 2 km "cells" and uses the ITM model to determine the presence or absence of TV service in each cell. To configure TVStudy's both contour and service field strength thresholds, we use the selected UL MCS SNR level (see Section IV-A) whichs is converted to its equivalent CNR level. We also adjust TVStudy's co-channel and adjacent-channel interference protection ratios by the difference between ATSC 1.0's 15 dB and the LDM-SHVC UL CNR level.

To obtain the existing coverage overlap with ATSC 1.0, a simplified approach using only noise-limited contours could be quite accurate because existing frequency planning interference rules consider a very low interference level at the edge of coverage, i.e. TV stations' coverage areas are, indeed, primarily noise-limited. However, in our scenario we extend stations' coverage by selecting a more robust MCS and keeping the same frequency allocation as of today, which leads to interference-limited service areas. This justifies a more accurate approach that considers at least terrain elevation, although being a more time consuming process. In this regard, the amount of noise-limited to interference-limited coverage shrinkage will depend on the density of broadcasters in the neighboring areas.

IV. Over-the-Air Coverage Overlap

In this section we present the results on predicted service coverage. First, we discuss the choice of bitrate and coverage for providing Mobile TV service in the considered two-layer LDM-SHVC transmission system. Second, we show the distribution of number of viewable major network affiliates with both today's ATSC 1.0 and with the ATSC 3.0 LDM-SHVC bitrate here considered. Finally, we focus on same-network coverage overlap results.

A. LDM Operating Scenario

As shown in (3), the coverage of each LDM layer will be determined by the interplay between the minimum SNR of each layer's chosen MCS $\{\gamma_{\mathrm{UL}}, \gamma_{\mathrm{LL}}\}$ and the injection level ρ. Current studies on LDM deployment have suggested values for ρ of 4 dB to 5 dB as a good trade-off between mobile UL coverage and the bitrate achievable with the LL at a coverage of 15 dB or less [4], [6], [13]. In [4], [6], it is also shown that under these considerations, the UL coverage for fixed rooftop receivers is much larger than for LL services at the 15 dB level.

In Table I we show three possible LDM UL service configurations depending on the bitrate required for the transmission of various bitrate program streams to mobile viewers. For each MCS, depending on the value of ρ, we show the resulting UL minimum CNR and the UL coverage for both handheld and rooftop reception. For rooftop reception we assume the existing OET-69 planning parameters [21] as used by the FCC. For Mobile TV reception, we assume an antenna gain of -7 dBi, a 10m to 1.5m 12 dB height loss, and a shadowing/fading margin of 3 dB [22]. Therefore, there is a 30 dB link budget difference between the mobile and the fixed reception scenarios.

As Table I shows, there is a modest drop-off in coverage area as we move to higher bitrates for the mobile (UL) PLP. At 2.0 Mbps, the mobile program would be limited to 720p resolution; at 4.1 Mbps, a 1080p full HD program should be possible. With ρ = 5 dB, the LL can provide around 15 Mbps at the 15 dB contour [4], sufficient when added to the 4.1 Mbps of the LL to provide a 4K-UHD program via SHVC to a rooftop receiver. Increasing ρ to provide even more power to the UL increases the coverage into rooftop receivers only modestly but substantially decreases the LL bitrate, which would could constrain the quality of the enhanced program stream to less than 4K-UHD. We choose a conservative set of parameters for studying the potential coverage overlap by assuming the higher bitrate alternative for the mobile UL layer, (2 dB required CNR) and limiting the UL power allocation to ρ = 5 dB.

Table I
LDM UL Required CNR and Coverage for Typical Mobile HD Video Bitrate Configurations

Bitrate	ρ = 5 dB			
	γ_{UL}	CNR	Coverage[1] Mobile	Coverage[1] Fixed
Low QPSK 3/15 2.0 Mbps	-4.3 dB	-2.6 dB	79 km	156 km
Medium QPSK 4/15 2.7 Mbps	-2.9 dB	-1.0 dB	76 km	150 km
High QPSK 6/15 4.1 Mbps	-0.5 dB	2.0 dB	72 km	138 km

[1] Coverage radius for a full-power TV station with transmit power equivalent to an omni-directional ATSC 1.0 coverage of 100 km.

B. Impact on Number of Viewable Network Affiliates

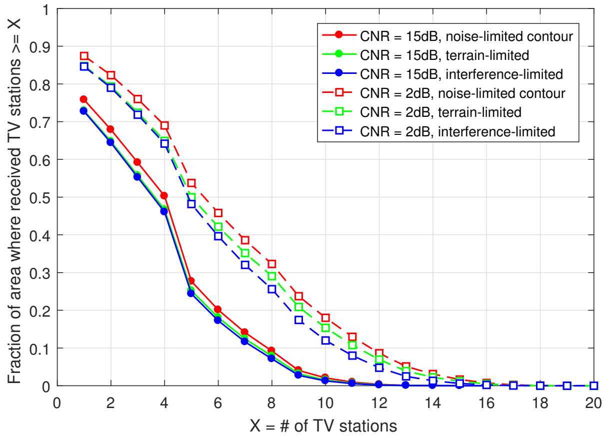
In Fig. 4 we present the results obtained with TVStudy for (a) the existing ATSC 1.0 15 dB service, and (b) the hypothetical ATSC 3.0 2 dB UL coverage. Here we show a cumulative density function for the number of affiliates of the four largest national broadcast networks in the U.S., ABC, CBS, NBC and Fox, receivable by area (Fig. 4a), and by population (Fig. 4b). In each figure, we show the results obtained using noise-limited contours, the ITM terrain-and-noise-limited results, and the terrain-and-interference-limited results. We can see that for 15 dB coverage all three cases show a remarkably similar distribution. On the other hand, with a CNR level of 2 dB, as discussed in III-B, we can clearly see the effect of interference in limiting the coverage enlargement. Furthermore, considering the terrain-and-interference-limited results, Fig. 4b shows that over 85% of the population receives four local TV affiliates, which are presumably one each of the four networks, less than 50% receive 5 stations or more, and thus have at least one redundant affiliate. With our ATSC 3.0 LDM-SHVC scenario, more than 95% of the population will have access to four full power broadcasters, and affiliate overlap increases substantially, with at least 75% of the population having access to a redundant affiliate, albeit potentially at no more than HD-1080p quality[9].

C. Same-network Coverage Overlap

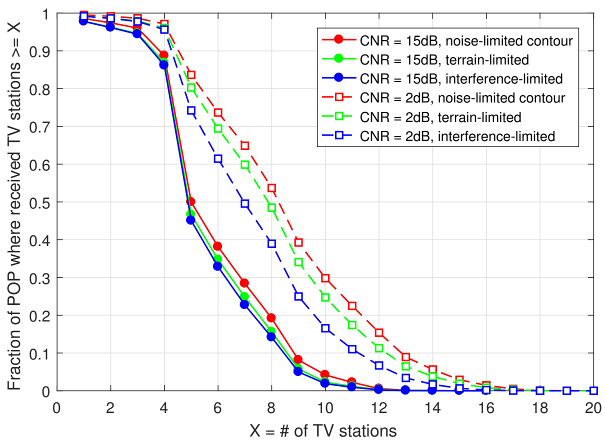
In Fig. 5 we show the geographic distribution of local TV affiliates of the ABC broadcast network. Here, Fig. 5a shows today's ATSC 1.0, while Fig. 5b shows our ATSC 3.0 scenario. We observe that even in today's ATSC 1.0 coverage the overlapping areas between affiliates is quite significant. We observe that the overlap between coverage areas is more prevalent in the eastern portion of the U.S. In the western part of the U.S. the population is much more scattered, so TV affiliates have greater geographic exclusivity. Although not shown here, in general we observe roughly the same pattern with the other three major networks —CBS, NBC and Fox.

In Fig. 6 we show for each broadcast network, the distribution of the number of different TV affiliates available across the U.S. population. For the ATSC 1.0 (15 dB) case, we see that 62–66% of the population is served by a single affiliate, 20–30% can choose between two, and a very small fraction has three or more choices. On the other hand, in the 2 dB case we observe that the fraction of the population with access to two affiliates grows to 35–40%, while 15–20% and $\tilde{5}$% would have access to three and four affiliates, respectively. In other words, a large majority of the population would have access to two or more affiliates of the same network, which may change the dynamics of retransmission consent negotiations.

[9] We have ignored here the role of LPTV and translators; actual network coverage today is larger than the coverage of Full-power and Class-A broadcasters alone. The need for translators in remote areas may be substantially reduced under this ATSC 3.0 LDM-SHVC scenario.



(a) Fraction of U.S. area



(b) Fraction of U.S. population

Figure 4. Complementary Cumulative Distribution Function (CCDF) of the number of affiliates available OTA across (a) the area and (b) the population of the Continental U.S., when considering the four largest national broadcast networks ABC, CBS, NBC and Fox.

V. Retransmission with Redundant Affiliates

As mentioned before, negotiation between local network affiliates and MVPDs over what consideration is due the broadcaster in return for retransmission consent are increasingly contentious [23]. When TV broadcasters are the only source of popular network programming in the area, they have high negotiation leverage and can demand high retransmission consent payments. MVPD carriage disputes occur when the parties fail to reach to an agreement, and this can lead to temporary or permanent programming blackouts. In this regard, MVPDs have called on the FCC for permission to negotiate carriage with willing out-of-DMA stations in the event of a blackout [23].

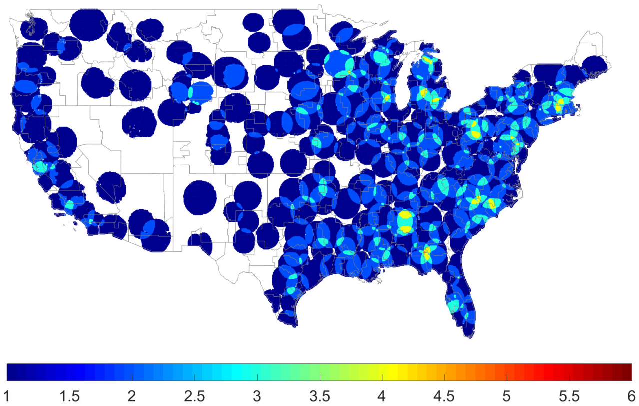
To illustrate the potential economic implications of same-network TV stations enlarging their coverage areas, we present a case study considering the Pittsburgh DMA and its neighboring DMA of Wheeling-Steubenville (W-S). As of January 1st, 2017, the Pittsburgh DMA is the 23rd largest DMA in the U.S. with 1,160,220 TV homes, while W-S ranks 158th with 128,720 TV homes. In Fig. 7 we show the counties that form each DMA and the ATSC 1.0 coverage area of each DMA's local CBS network affiliate (KDKA-TV and WTRF-TV, respectively). We clearly observe that neither coverage area really matches with each DMA. In the case of KDKA-TV, it does not cover the entire Pittsburgh DMA, and also has substantial coverage overlap with counties in the neighboring Wheeling-Steubenville DMA. In the case of WTRF-TV, it covers its entire DMA and many areas beyond.

As discussed in II-B, contractual agreements between networks and their affiliates, supported by FCC rules on distant signal importation, limit the ability of an MVPD to carry broadcast signals from a network affiliate outside the DMA in which the MVPD has its footprint. This is, in case of a dispute over retransmission consent fees with KDKA-TV, an MVPD in the Pittsburgh DMA cannot import the signal of the New York CBS affiliate or the Los Angeles CBS affiliate. However, an MVPD can reach an agreement with out-of-DMA CBS affiliates whose signal is deemed SV in counties where the MVPD has a presence.

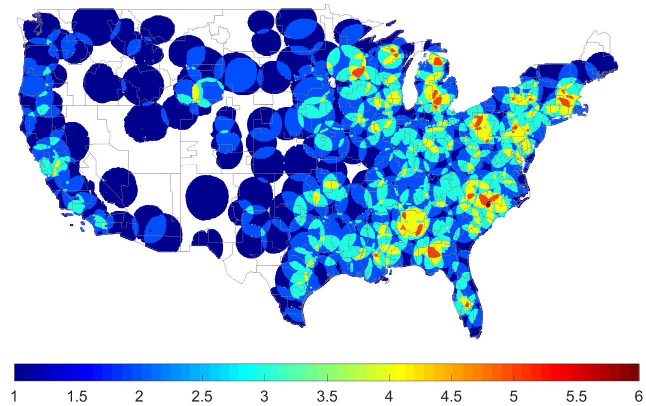
Coverage overlap is a necessary, but not sufficient condition for a broadcaster to be SV in a county outside its DMA. Wheeling-Steubenville's WTRF-TV station has significant OTA coverage in 10 of 16 counties of the Pittsburgh DMA, but according to the FCC, it is only SV in four of them: Greene PA, Washington PA, Monongalia WV, and Preston WV. On the other hand, Pittsburgh's KDKA-TV station has significant coverage in 8 out of 11 of the Wheeling-Steubenville DMA counties, and it is SV in all of them. Factors other than coverage which influence SV status may include exclusive access to regional sports programming, or the quality of locally produced programming.

When, as a result of coverage overlap, a second affiliate of the same network becomes SV in an MVPD's service area, the MVPD now can threaten to carry network programming from the out-of-DMA TV station, if the latter is willing to accept a lower retransmission consent payment. The bargaining power of the in-DMA affiliate is substantially reduced as it loses its monopolistic bargaining position. Thus, if KDKA-TV demands too high retransmission consent fees from an MVPD serving, e.g., Washington County, that operator could decide to conclude a retransmission consent agreement with WTRF-TV at a more favorable rate as an alternative, and its subscribers would suffer no loss of CBS network programming. However, subscribers might still suffer if KDKA-TV has exclusive rights to important non-network programming such as Pittsburgh sports teams. Similarly, MVPDs within the Wheeling-Steubenville DMA, could choose to carry KDKA-TV in lieu of WTRF-TV.

In Fig. 8 we show the hypothetical case when KDKA-TV uses the proposed ATSC 3.0 SHVC-into-LDM configuration and thus substantially enlarges its coverage area. In this scenario, we see that KDKA-TV would have significant coverage in all of the counties in the Wheeling-Steubenville DMA. If OTA KDKA-TV viewers were sufficient for the station to

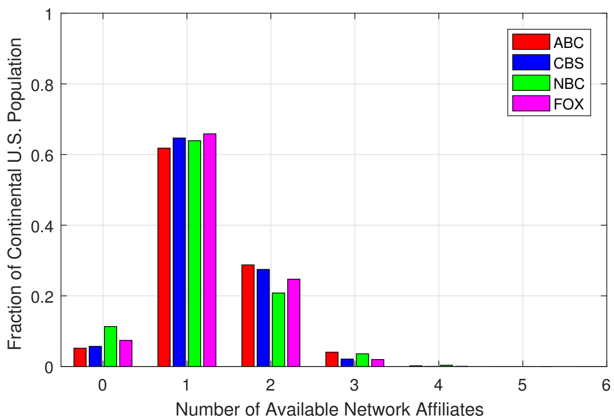


(a) CNR = 15 dB

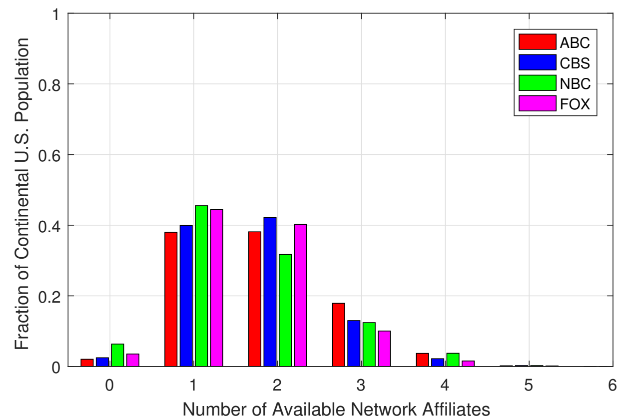


(b) CNR = 2 dB

Figure 5. Nationwide coverage of the ABC broadcast network for the two scenarios here considered.



(a) CNR = 15 dB



(b) CNR = 2 dB

Figure 6. Distribution of the fraction of population with access to redundant local TV stations affiliates for each of the two scenarios and the national broadcast networks here considered.

be SV, then KDKA-TV could have the incentive to undercut WTRF-TV across its whole DMA. As of today, KDKA-TV is SV in all counties where it has some OTA coverage.

In general we observe that large market broadcasters are more likely to be classified as SV when they are receivable in smaller adjacent markets than vice versa[10]. While large market stations will thus have the greater opportunity to compete for retransmission consent revenues in smaller markets, they are also more likely to demand higher per subscriber fees. Conversely a small market broadcaster who is successful in becoming SV may have greater incentive to undercut the fees imposed by large market broadcasters because of the greater potential percentage increase in revenue.

VI. Forecasting Significantly Viewed Status

OTA coverage by itself does not tell if an increase in coverage overlap between same-network affiliates will create issues to the existing retransmission consent regime between TV stations and MVPDs. Only when a TV station gets classified as significantly viewed (SV) outside its DMA, can it then realistically enter into negotiations with an MVPD despite being technically an out-of-market station. Under current regulations, the SV status gives TV stations the right to be treated as local with regards to retransmission consent. Otherwise, it would be very difficult for an out-of-market TV station to enter into negotiations due to the network non-duplication rule discussed in Section II-C. Thus, it is important to understand if mere increase in OTA coverage makes it more likely for a TV station to be classified as SV.

In this section we work on characterizing the statistical relationship between TV stations' out-of-DMA SV status and their OTA coverage; and then use that relationship to forecast SV status in the scenario where TV stations increase their coverage areas via ATSC 3.0's LDM+SHVC. SV status depends on OTA viewership, and OTA viewership in turn depends on OTA coverage, so we expect OTA coverage to be a strong predictor. However, OTA coverage may not necessarily be the only predictor, or even the strongest. For these reasons,

[10]We observed a similar pattern with the Youngstown, OH CBS affiliate (not shown here), which is located ~120 km to the northwest of Pittsburgh PA.

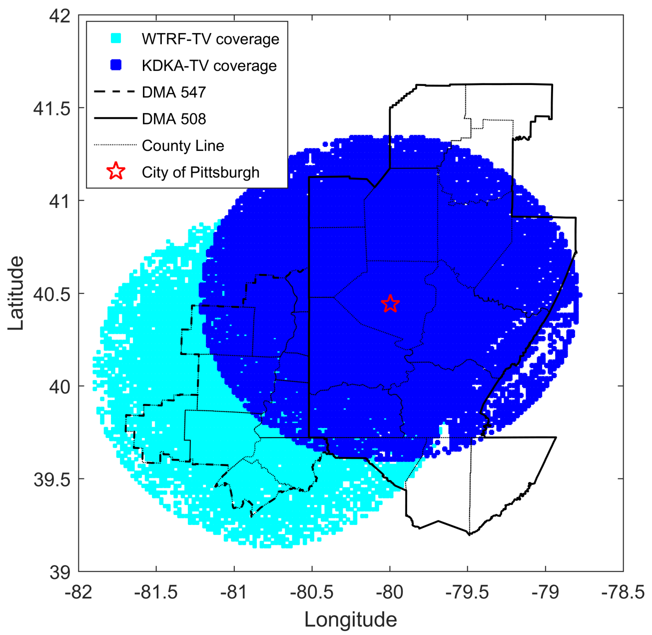


Figure 7. ATSC 1.0 coverage areas of the CBS network affiliates in DMA-508 (Pittsburgh) and DMA-547 (Wheeling-Steubenville).

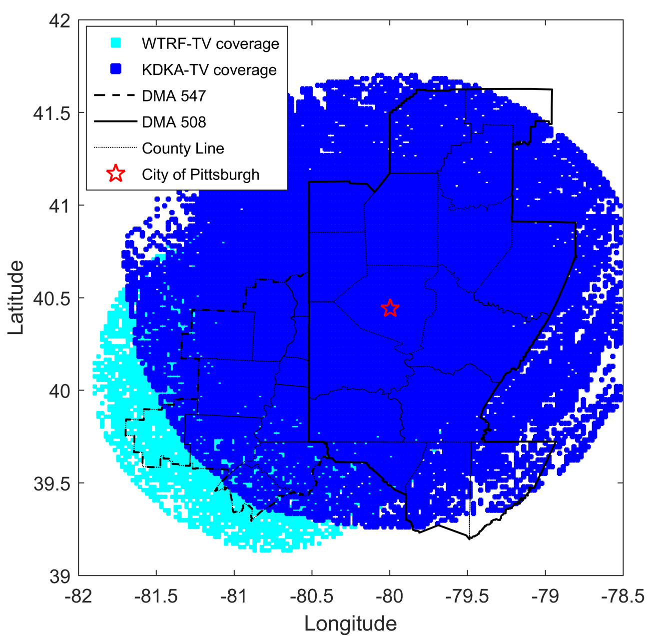


Figure 8. ATSC 3.0 LDM coverage area of the DMA 508 (Pittsburgh) CBS affiliate (KDKA-TV) vs. the ATSC 1.0 coverage area of the DMA-547 (Wheeling-Steubenville) CBS affiliate (WTRF-TV).

we consider a model where OTA coverage is one of the several possible independent "SV status" predictors X_i, and "SV status" is a binary/categorical dependent variable Y, i.e. we build a dataset of the form $(Y; \mathbf{X}) = (Y; X_1, X_2, \ldots, X_k)$.

Having the dataset available, the perhaps first and simplest approach to characterize the OTA coverage vs SV status relationship would be by using logistic regression. However, despite being an useful starting point, logistic regression has a significant number of limitations. Most notably, logistic regresssion assumes the argument to the logistic function is a linear combination of the independent variables, i.e. it imposes a linear decision boundary, which may not be the best fit. To better unravel the coverage-SV status relatioship, we will also use the more robust machine learning technique called *random forests* [24] [11]. Because random forests are based on *classification trees*, which are non-parametric by definition, they can model arbitrarily complex relationships between variables without making any hard a-priori assumption [24] [11].

A. Preliminaries

1) Logistic Regression: Logistic regression is is a technique for predicting a categorical outcome. Logistic regression belongs to the family of generalized linear models, in which the probability of a particular outcome is "linked" to a linear function of the predictor variables via the standard logistic sigmoid function [11]; i.e., Y is estimated as

$$\begin{aligned} \tilde{Y} &= f_{LR}(\mathbf{X}) \\ &= \mathbb{1}\left\{\Pr\left(Y = 1 \mid \mathbf{X}\right) > 0.5\right\} \end{aligned} \tag{4}$$

where $\mathbb{1}\{\}$ is called the indicator function, and the outcome probability, conditioned on the observed dataset, is given by

$$\begin{aligned} \Pr\left(Y = 1 \mid \mathbf{X}\right) &= \operatorname{logit}^{-1}(\beta \cdot \mathbf{X}) \\ &= \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k)}}, \end{aligned} \tag{5}$$

where β is a vector of coefficients for each attribute/predictor, obtained via maximum likelihood (ML) [11].

2) Classification Trees: With tree-based methods, the attribute/predictor space is partitioned into a set of regions R and a simple model (in this case a constant of value 0 or 1) is fit within each of them [11]. Within a tree, the choice of which variables to split and at which specific split-points is made to achieve the best classification rate. After the first split, then one or both of the newly created R regions are split into two more regions, and this process is continued until some stopping rule is applied [11]. See Fig. 9. Therefore, with classification trees the value of Y is estimated as

$$\begin{aligned} \tilde{Y} &= f_{CT}(\mathbf{X}) \\ &= \sum_{m=1}^{M} \mathbb{1}\left\{\mathbf{X} \in R_m\right\} \end{aligned} \tag{6}$$

3) Random Forests: As an extension of classification trees, random forests is an ensemble method that combines the fit from many hundreds or thousands of individual classification trees to get an overall more robust predictor. Random forests uses bootstrap aggregation, a general statistical technique for reducing the variance of an estimate [11]. Given a dataset of size N_{obs}, random forests generates B new datasets $\mathbf{X}^{(i)}$ of size $n < N_{\text{obs}}$ via uniform sampling with replacement. For computing the trees associated with each $\mathbf{X}^{(i)}$, only $p < k$ attributes are randomly selected for each one of them (usually

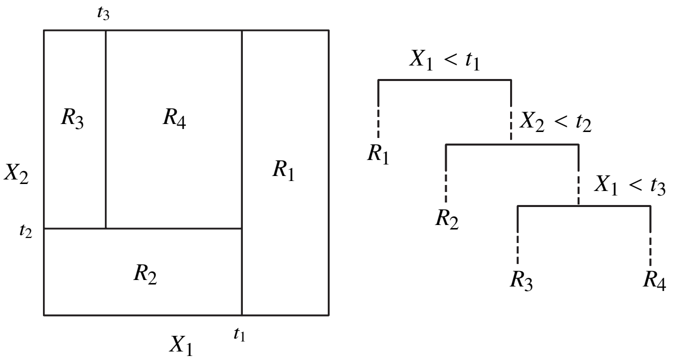


Figure 9. Example of a simple classification tree. The partition of the attribute region is shown on the left, while the equivalent binary split tree is shown on the right. Branches and partitions within the tree are chosen to minimize the overall classification error.

Table II
INDEPENDENT VARIABLES/PREDICTORS

Symbol	**Description**
Cov_{POP}	Out-of-DMA TV station's county population coverage
$\text{Cov}_{\text{local}}$	Local TV station's county population coverage
$\text{DMA}_{\text{log-ratio}}$	Logarithmic ratio between local and out-of-market population
$\text{Dist}_{\text{TV-county}}$	Distance between out-of-DMA TV station and county's geographical centroid
TV_{Lat}	Out-of-DMA TV station's latitude, in degrees
TV_{Lon}	Out-of-DMA TV station's longitude, in degrees
Network	Categorical variable representing affiliation with ABC, CBS, NBC or Fox of both local and out-of-DMA TV station.
Same State	Categorical variable, whether there is more than one out-of-market TV station, of the same network, with some coverage of the county.
Third	Categorical variable, if there is or is not more than one out-of-market affiliate of the same network with coverage in a county.

$p = \lfloor\sqrt{k}\rfloor$), i.e. $\mathbf{X}_p^{(i)} \subset \mathbf{X}^{(i)}$. Therefore, random forests estimate Y as

$$\begin{aligned} \tilde{Y} &= f_{RF}(\mathbf{X}) \\ &= \mathbb{1}\left\{\frac{1}{B}\sum_{i=1}^{B} f_{CT}^{(i)}(\mathbf{X}_p^{(i)}) \ > 0.5\right\}, \end{aligned} \tag{7}$$

i.e. the value of Y is assigned given the majority vote among what individual trees predict.

B. Data Analysis

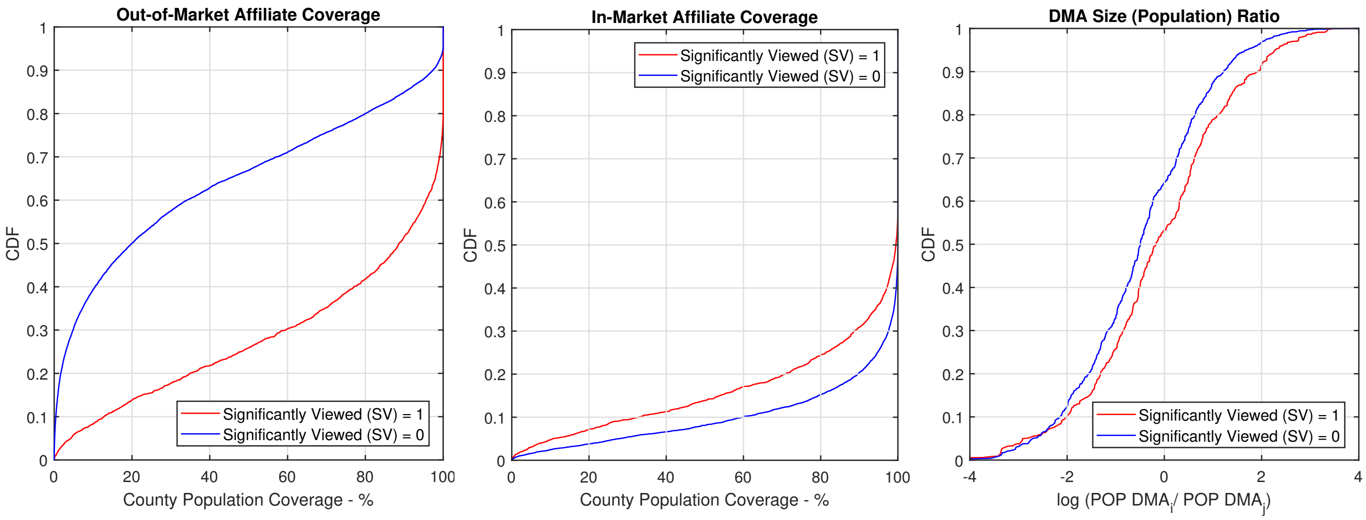
For our analysis we consider all {TV station, out-of-DMA-county} pairs where the TV station's ATSC 1.0 population coverage is greater than zero. We also add a small number of TV station/out-of-DMA-county pairs where the coverage is null but the TV station is reported by the FCC as SV in that county; we do not discard these cases from the dataset as random forest is known to be robust against outliers [11]. With these considerations, our constructed dataset is composed of 19,034 {TV station, county} pairs across all four networks (ABC, CBS, NBC and Fox), wherefor 17.6% of these pairs the station is considered SV within the associated county, and not SV otherwise. Note that there are a total of 3,007 counties in the Continental U.S.; some counties may have non-zero coverage from multiple affiliates of the same network for which the county is out-of-market for each of them.

For several candidate independent variables X_i, we examine the CDF of these variables across our dataset conditioned on SV = 0 or 1. In Fig. 10a we show the cumulative distribution function (CDF) of county population coverage conditioned on the TV station/county pair being classified as SV = 1 or not. As expected, we observe that counties classified by the FCC as SV tend to have a much higher coverage from the out-of-DMA TV station than is the case when the counties are not marked as SV. However, from the same figure, it is quite clear that population served cannot be by itself the only explanatory variable: we observe that there are poorly covered counties where the out-of-DMA TV station is SV, and highly covered counties where the out-of-DMA TV station is not SV. In Fig. 10b we plot the CDF of OTA county coverage of the in-market affiliate TV station, conditioned on the out-of-DMA TV station/county pair being SV. We observe that counties marked as SV tend to have a lower OTA coverage of the in-market TV station, and vice-versa, counties not marked as SV tend to have a higher OTA coverage of the in-market TV station, i.e: where the in-market local affiliate does not cover the county well, it is more likely that an out-of market affiliate will be SV. We hypothesize that the ratio of the population of the DMA of the out of market TV station as compared to the population of in-market DMA may also be a predictor. Viewers are more likely to watch an out-of market affiliate when that affiliate is located within a relatively larger DMA. Due to economies of scale in broadcast distribution, larger markets are usually associated with higher-quality local content, higher-quality and more relevant local news, programming associated to large local sport teams, etc. In Fig. 10c we show the logarithmic ratio of the size of the local DMA vs the DMA size of the out-of-market TV station: a positive value indicates that the DMA of the "invading" network affiliate is larger than the "invaded" DMA. In this regard, Fig. 10c suggests that this ratio may be significant. All in all, Fig. 10 confirms that, at least, "directionally correct" relationships do exist. Table II summarizes the variables we will consider in the rest of our analysis.

C. Model Calibration

We compare the predicted SV status vs actual SV status for both logistic regression and random forests models. We analyze the stregth of these results using the statistics/machine learning concepts of *confusion matrix* and the *receiver operating characteristic* (ROC) curve.

1) Confusion Matrix: The performance of a classification method can be typically evaluated by a confusion matrix, where the columns of the matrix are the predicted class and the rows of the matrix are the actual class. In the confusion matrix, the number of negative examples that are correctly classified as negatives are called True Negatives (TN), while the number



(a) (b) (c)

Figure 10. Cumulative Distribution Function (CDF) of (a) Out-of-DMA county population coverage (b) In-DMA county population coverage (c) logarithm of the ratio between size of DMA of the Out-of-DMA TV station vs the size of the DMA of the local TV station in terms of total population.

of negative examples incorrectly classified as positive are called False Positives (FP). Conversely, the number of positive examples that are correctly classified as positives are called True Positives (TP), while the number of positive examples incorrectly classified as negatives are called False Negatives (FN).

In Table III we show the classification results of the logistic regression model applied to our dataset, using the standard classification cutoff value of 0.5 as in (4). For the logistic regression model, we use all Table II variables but variables TV_{lat} and TV_{lon}. For this, we apply the `glm` function available in R®. Results show that all but variables “Network” and “Same State” are statistically significant at the $p < 0.001$ level. Overall, the most important aspect to observe is that the resulting model is extremely good at identifying TNs, with a TN rate (TNR) of 98.1%. However, we expect a model that can correctly predict SV status, (TP) whereas the logistics model has a TPR of 8.8%.

In Table IV we show the classification results of the random forests model. For this, we apply the `randomForest` function, also available in R®. Once again, the resulting model is extremely good at identifying TNs with a TNR of 96.6%; however we also observe a quite dramatic improvement in identifying TPs, compared to logistic regression, as the TPR increases to 52.2%. For this model, Fig. 11 shows the *variable importance*. Variable importance is, in general, an indication of which independent variables are most useful for predicting the outcome variable [11]. In Fig. 11 we present variable importance in terms of the mean decrease in accuracy and the mean decrease in gini coefficient measures. Mean decrease in accuracy measures the random forest’s loss in accuracy due to the exclusion or permutation of the variable. Mean decrease in Gini coefficient measures how each variable contributes to the homogeneity of the nodes and leaves in the resulting random forest. For both metrics, OTA population coverage, Cov_{POP}, is the most important predictor of SV status. However, we find that other variables are significant predictors as well. Finally, as with logistic regression, variables “Network” and “Same State” show a relatively low statistical significance.

2) Receiver Operating Characteristic (ROC): The receiver operating characteristic (ROC) curve is a standard technique for summarizing the performance of a classifier by showing the trade-off between its attainable true positive rate (TPR) vs a given false positive rate (FPR) and vice-versa. TPR and FPR are depicted in the y-axis and x-axis respectively, and the curve is generated by varying the classification cutoff value from its defaul value 0.5 over the entire [0,1] range. The more concave the ROC curve, the better the performance of the classifier, so the Area Under the ROC Curve (AUC) is also a well-accepted traditional performance metric for a classifier. In Fig. 12 we compare the ROC curves for both the logistic regression and the random forest models. For each curve, its value at the classification cutoff 0.5 represents the results shown in Table III and Table IV respectively.

In general, ROC curves represent an infinite family of confusion matrices, each of which may represents a different trade-off between TPs and FPs [11]. In our study, we want to predict SV counties as accurately as possible while avoiding overestimating them. In the case of logistic regression, we find that both TPR and FPR performances are surprisingly poor. Using a new classification cutoff of 0.2 with the logistic model would increase the TPR to roughly 70%, but it would also increase the FPR to around 30%, which would, in our opinion, extremely overestimate the number of SV counties in the ATSC 1.0 training dataset. On the other hand, with random forests we could increase the TPR performance from 52% to

almost 75–80% by using a classification cutoff value of 0.3, but that only increases the FPR towards the 10% range.

In both ROC curves in Fig. 12 we observe that the default classification cutoff value 0.5 is on their lower part. This signals that both models, as is, have problems identifying positive vs negative SV counties, as we also observed in Table III and Table IV. The default performance measure to train machine learning classification algorithms is the *total predictive accuracy*, defined as (TP + TN)/(TP + FP + TN + FN). This usually assumes that datasets are balanced and that, for the practitioner, the misclasssification costs between TPR and FPR are somewhat equivalent. This is not our case: our data is both imbalanced (82/18) and we prefer to have a lower FPR at the expense of TPR, as a conservative predictive measure. One effective way to deal with imbalance is to use oversampling/undersampling techniques, as a way to further increase the TPR without decreasing FPR performance.

3) SMOTE—Synthetic Minority Over-sampling: Building an effective classification model is challenging if the input dataset is imbalanced. In this case, SV = 0 samples quite outnumber the number of SV = 1 samples. By maximizing total accuracy, a machine learning techniques will favor the majority class and would be ineffective at identifying examples of the minority class, as we already observed. One effective method to deal with this issue is SMOTE - *Synthetic Minority Over-sampling Technique* [25]. SMOTE is a sofisticated approach that adds new artificial minority-class synthetic samples by extrapolating between preexisting minority samples via k-nearest neighbors (KNN) [25] —rather than simply duplicating (oversampling) original ones. For this, we use the `SMOTE` function available in R®.

In Fig. 13, and now leaving aside logistic regression, we compare the previous random forests result in Fig. 12 with the curve obtained by using SMOTE. Applying SMOTE means that we create an augmented dataset —that contains both the samples of the original dataset and the new synthetic samples—that we then use to train a new random forest model. In Fig. 13 we show the ROC curves using both the syntetic dataset and the original dataset. It is clear that using SMOTE to balance the dataset has not only greatly increased the TPR performance of the model, but also by returning the classification cutoff value 0.5 back to the upper part of the ROC curve.

Table III
LOGISTIC REGRESSION CONFUSION MATRIX

		Predicted SV 0′	Predicted SV 1′	**total**
Actual SV	**0**	TN 15,407 – 98.1% –	FP 293 – 1.9% –	15,700
Actual SV	**1**	FN 3,053 – 91.3% –	TP 291 – 8.7% –	3,334
	total′	18,460	584	

Table IV
RANDOM FORESTS CONFUSION MATRIX

		Predicted SV 0′	Predicted SV 1′	**total**
Actual SV	**0**	TN 15,171 96.6%	FP 529 3.4%	15,700
Actual SV	**1**	FN 1,597 47.8%	TP 1,749 52.2%	3,334
	total′	16,768	2,276	

D. Forecast Results

The main purpose of this section is to forecast SV status in the scenario where TV stations increase their coverage areas via ATSC 3.0's LDM+SHVC. With the obtained SMOTE-calibrated random forests model, we use TVStudy to recalculate TV stations' OTA coverage across the Continental U.S., now considering a LDM-SHVC upper layer CNR value of 2 dB. We then input this result to the previously trained random forests model. The projected increase in SV status, in terms of TV station/county pairs, is shown in Fig. 14. To perform a sensible sensitivity analysis, the SV forecast result is expressed as a function of the classification cutoff value used in the model. Here, each classification cutoff value represents a specific trade-off between TPR and FPR, as previously shown in Fig. 13. We choose cutoff values between 0.4 and 0.7, which in turn, they represent a range of TPR between 88% and 99% and a range of FPR between 1.5% and 5% over the training dataset. As mentioned before, we choose low FPR values as we aim to not overestimate the number of additional SV counties. In what we consider a quite conservate estimate, our results predict that SV status will increase in 100% or more with ATSC 3.0's LDM-SHVC.

VII. CONCLUSIONS

U.S. TV broadcasters moving to ATSC 3.0 and choosing to carry separate PLPs optimized for mobile and fixed receivers, will find that the mobile signal reaches fixed receivers over a much larger coverage area than today's ATSC 1.0 service. Increased coverage leads to increased overlap between affiliates of the same national network. Where today that overlap occurs for less than 40% of the population, in this study we conservatively estimate the extent of the increased competitive overlap and find that as much as 75% of the

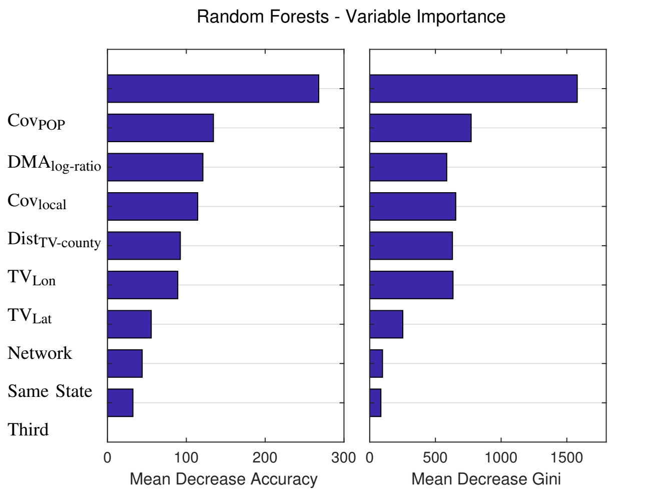


Figure 11. Random Forests' variable importance measure. To the left, based on mean decrease accuracy. To the right, based on mean decrease in Gini. Variables shown in descending order in terms of the former. For both metrics, OTA population coverage, Cov_{POP}, is the most important predictor of SV status, but other variables are also significant.

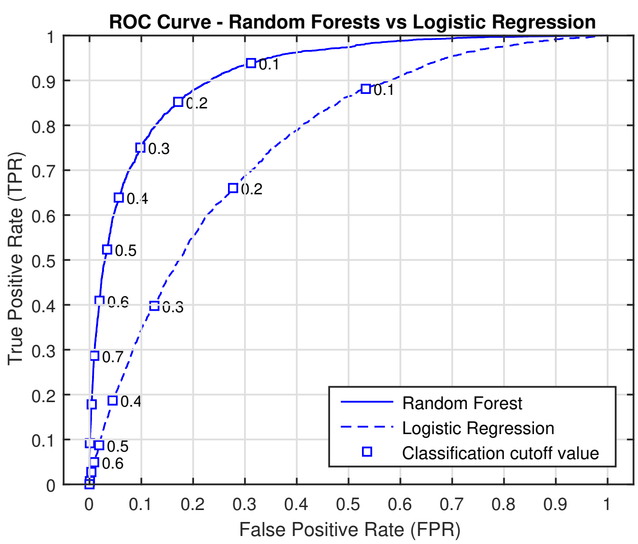


Figure 12. Classification performance comparison between random forests model and logistic regression model in terms of the ROC curve. For the logistic regression model, the area under the curve (AUC) value is 0.76. For the random forests model, the AUC value improves to 0.85.

U.S. population will have access to at least one redundant major network affiliate, and that each major national broadcast network would be providing, on average, two or more affiliates to approximately 60% of the population.

The ability of a network affiliated broadcaster to extract retransmission consent revenues from MVPDs which carry its signal rests in large part on its exclusive carriage of popular network programming within its market area. Increased overlap implies that MVPDs may have increased ability to pit affiliates against each other in these negotiations, without fear of losing access to network content, leading to reduced

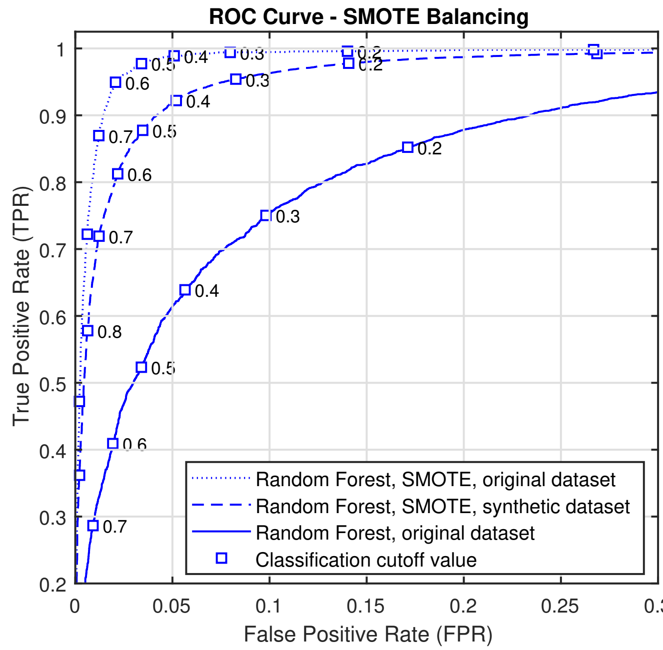


Figure 13. Classification performance comparison between random forests "as-is" vs random forests after SMOTE oversampling. For random forests "as-is", AUC=0.85. Applying SMOTE oversampling, AUC=0.92 when considering the synthetic dataset, and AUC=0.96 when considering the original (unbalanced) dataset.

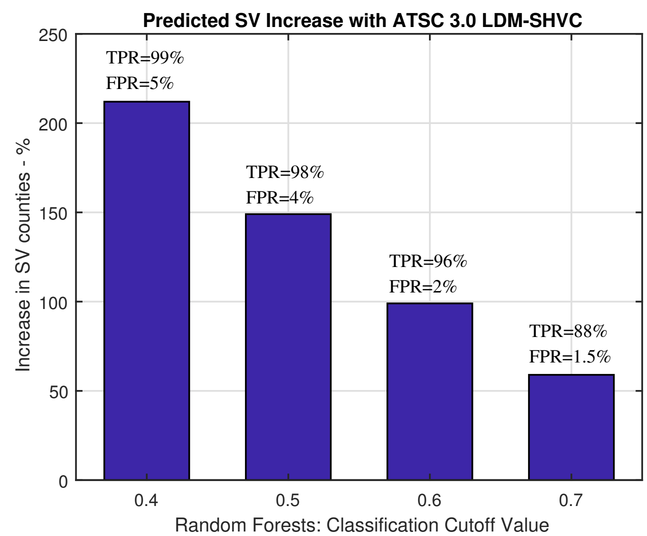


Figure 14. Projected increase in SV status, in terms of TV station/county pairs, as a function of the random forests classification cutoff value. Each classification cutoff value represents a specific trade-off between TPR and FPR. A quite conservate estimate predicts that SV status will increase in 100% or more with ATSC 3.0's LDM-SHVC.

retransmission consent revenues for broadcasters.

Complex U.S. rules condition this negotiation on overlapping affiliates being *significantly viewed* outside their market area, a status based on measurements of over-the-air viewership of the overlapping affiliate by out-of-market households. In this paper, we create a model for predicting SV status

as a function of coverage and other factors, and train the model using existing coverage of ATSC 1.0 broadcasters and current SV designations. When we apply the model to the enhanced coverage we predict for ATSC 3.0 broadcasters who choose to broadcast a PLP optimized for mobile reception, we conservatively estimate that the number of SV station-county pairs will at least double. Thus, the impacts on retransmission consent negotiations that we predict are likely to be economically significant. At the same time, some of the regulatory implications of SV status depend in part on FCC rules which the Commission is currently reconsidering [26]. Nevertheless, parts of the current framework are prescribed by statute [19] and cannot be undone by the FCC on its own.

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