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Reducing spectrum use in traditional and SFN-based television for uniform and non-uniform deployments

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ABSTRACT

During the last few years, reclaiming TV spectrum for mobile broadband use has been a hotly debated topic in the telecommunications policy agenda. This paper evaluates two ways to improve spectrum efficiency to today's noise-limited single-transmitter broadcast television approach. One way is to increase the transmit power of each broadcaster's only transmitter. The other way is to replace that single transmitter with a multi-transmitter low-power low-tower (LPLT) single frequency network (SFN). In order to quantify their potential benefits, two different scenarios are considered. First, this paper presents the results obtained for a large region in which broadcasters are uniformly distributed, so that the number of TV broadcasts that can be received is roughly the same at any location. In this case, results suggest that increasing power of traditional single-transmitter broadcasters could reduce the amount of spectrum needed for TV by up to 30%, and would be cost-effective for population densities above 30 per square km. A switch to SFNs could reduce the amount of spectrum needed for TV by roughly 60%, but at a higher cost. Results suggest that the LPLT SFN approach could be cost-effective for regions with uniformly distributed broadcasters and population densities above 120 per square km. The study then quantifies spectrum efficiency gains in regions where broadcasters are not uniformly distributed. In particular, it considers the case where U.S. broadcasters in the UHF band continue to serve their coverage areas as of 2015. In this case, the amount of spectrum that can be freed from TV throughout the entire nation using these two approach is considerably smaller, but some additional bands can be freed from TV throughout much of the nation. Moreover, most of these spectrum gains can be obtained when only a minority of broadcasters change their technical approach.

1. Introduction

Spectrum policies have long minimized the cost per area covered of TV transmission while ignoring the opportunity cost of the spectrum. They do that in two ways. First, by choosing the single-transmitter high-power high-tower (HPHT) traditional broadcasting approach, in which elevated sites have to transmit in the range of tens to hundreds of kW in order to cover a large enough —and economically meaningful— area. Second, by using a very conservative frequency reuse approach by making sure that the distances between broadcasters' coverage areas are so large that the effect of interference at the edge of coverage is negligible.

One alternative to this is the use of low-power low-tower (LPLT) Single Frequency Networks (SFN), where multiple synchronous transmitters send the same signal over the same frequency channel, at much lower heights and transmit power (Lewin et al., 2014;

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CEPT-TG6, 2014; Huschke, Sachs, Balachandran, & Karlsson, 2011; Mattsson, 2005). With LPLT SFNs, the building and operational costs are greater, but so is the potential spectrum efficiency. Also, either with LPLT SFNs or with traditional broadcasting the distance between coverage areas could be reduced while keeping coverage areas the same by increasing transmit power, and thereby tolerating more interference at the edge of coverage. Setting the distance between co-channel broadcasters such that interference is negligible might be the right strategy if the goal is to minimize broadcast stations' transmission costs, and if spectrum is considered to be so plentiful that its cost can be ignored. That may have been the world we lived in when regulatory bodies started granting TV licenses, but it is certainly not the world today (Zander & Mahonen, 2013), which is in part why this work revisits this issue and examines the effectiveness of an interference-limited (rather than noise-limited) approach.

Lately, the use of LPLT SFNs has been actively discussed as a means to reclaim a significant amount of TV spectrum. The first formal proposal to change the U.S. broadcast TV transmission architecture to LPLT SFNs was in 2009 (CTIA, 2009), in the context of the 2010 U.S. National Broadband Plan (NBP) (FCC, 2010a). However, LPLT SFN deployments will only become practical in the short term once the new Advance Television System Committee (ATSC) 3.0 TV transmission standard is adopted (ATSC-PT2, 2011; ATSC-TG3, 2013). In Europe, LPLT SFNs has also been considered as a possible way to reclaim a significant amount of spectrum in the discussion of the future of the UHF TV band (Lamy, 2014; CEPT-TG6, 2014; Lewin et al., 2014).[1] Although some forms of SFNs have already been deployed in Europe for a few years, these SFNs have been of the HPHT type (Li et al., 2015; Malmgren, 1997; Meabe, Gil, Li, Velez, & Angueira, 2015; Rebhan & Zander, 1993), as opposed to the more spectrum efficient cellular-like LPLT SFNs considered here and in previous related literature (See Section 2).

This work quantifies the effectiveness of either boosting transmit power or switching to LPLT SFNs to increase spectrum reuse without significantly changing the population served or technical capabilities of current U.S. TV broadcasters. One of the ways this work differs from the existing literature, e.g. (Huschke et al., 2011; Shi, Sung & Zander, 2014; Shi, Obregon, Sung, Zander, & Bostrom, 2014), is that it assumes broadcasters keep the same spectrum licensing model with the same exclusive access rights to their own frequency channel. It is only by comparing spectrum efficiency of LPLT SFNs and traditional broadcasts when both offer the same coverage areas and bandwidths that all of the results of this work are because of the transmission upgrade, and not because of other factors such as bitrate management, source coding, carrier aggregation, etc. Moreover, while this is not the only possible scenario, it is certainly a realistic one, since this is the scenario that requires the fewest changes in business strategy for broadcasters and in spectrum policy for regulators.

The cost-effectiveness of these alternative technical approaches will depend on how the number of broadcasters is distributed across the region under consideration. Thus, this work considers two cases. In the first, this work assumes that all TV service areas are the same size and broadcasters are uniformly distributed, i.e. the number of TV signals that a viewer in any location can receive is roughly the same at any location throughout a region that is much larger than a TV service area. Some parts of the U.S. and other nations may contain broadcasters that are roughly uniformly distributed, but this is certainly not the case everywhere. In a second case, this work considers a highly heterogeneous deployment. To represent such a case, this work uses the Continental U.S., considering all TV stations in the UHF band. Here, the number of UHF TV stations varies tremendously: from 2 to 3 in the smallest of the 210 U.S. TV markets, to 22 in the (#1) New York Market. In the U.S., higher population density means more advertising revenues per square km served, which means that more broadcasters can operate at a profit in such areas. Also note that TV spectrum assignment in the U.S has followed a first-come first-served site-based licensing approach, where a license can be granted in any place as long as spectrum is available.[2] By comparing and contrasting the results of these two cases, this work will discuss insights and implications of the differences in the effectiveness of the technology.

To analyze the uniform deployment case, this paper develops a theoretical model that considers a single frequency channel that is used by multiple identical broadcasters, each of which serves coverage areas of equal size through either a traditional single-transmitter approach or by a LPLT SFN. The model assumes this band is used only for TV, so it measures the extent and efficiency of the spectrum use as the fraction of total area that falls within a TV coverage area. The model shows that both alternatives may increase spectrum efficiency, and it calculates the minimum average population density at which the value of spectrum freed would exceed the cost of changing technology. For doing this, we assume that a traditional television station is in place, and estimate the net present value (NPV) of both the cost of upgrading broadcasting infrastructure, if any, and the change in long-term operating costs when using a cost-minimizing design for each broadcaster. We do not consider the cost to consumers who might need to purchase a converter box, in part because the cost of converters would be negligible when compared to the other costs, as shown in (Bettancourt & Peha, 2015). Moreover, a shift to LPLT SFNs in the U.S. could accompany the adoption of ATSC 3.0, which would require TV households to invest in TV receivers or converter boxes regardless of whether LPLT SFNs are adopted or not.

To analyze the non-uniform deployment case, a different approach and model is used. Here, the number of channels that must be assigned to at least one TV broadcaster somewhere in the nation will be determined in large part by the needs of the few cities with the most TV stations, making it more difficult to clear channels nationwide. Moreover, coverage areas also vary considerably from station to station, so the model uses the actual coverage area sizes and locations of UHF TV broadcasters. When analyzing the effect of increasing transmit power, the model assumes that powers of all broadcasters are increased by the same number of dB. This gives a useful bound on effectiveness, although it is clear that a more complex algorithm could be even more cost-effective. For the case of LPLT SFNs, the model similarly assumes that all broadcasters switch to LPLT SFNs. A modified version of U.S. Federal

[1] In contrast to the U.S., LPLT SFNs are already possible in some parts of Europe that have already adopted the Digital Video Broadcasting Second Generation Terrestrial Standard (DVB-T2).

[2] In this way, current allocations may reflect what fits the traditional noise-limited technical approach rather than what is desired by TV broadcasters. Thus, the assumption that coverage areas remain unchanged will somewhat favor the noise-limited approach.