LOCAL CONTENT DELIVERY IN SFNS USING LAYERED DIVISION MULTIPLEXING (LDM)

J. Montalban[1], P. Angueira[1], M. Velez[1], Y. Wu[2], L. Zhang[2], W. Li[2], K. Salehian[2], S. Laflèche[2] , S-I Park[3], J-Y Lee[3], H-M Kim[3], Dazhi He[4], Yunfeng[4] Guan, Wenjun Zhang[4]

[1]University of the Basque Country, Spain;
[2]Communications Research Centre, Canada
[3]Electronics Telecommunications Research Institute, Korea
[4]Cooperative Innovation Center of Shanghai Jiaotong University/National Engineering Research Center on DTV, China

ABSTRACT

Single Frequency Networks (SFNs) are considered the optimal network configuration to maximize the spectrum efficiency and to minimize the co-channel interference problems in the advanced broadcasting planning. As a matter of fact, they have been widely used in the European countries since the dawn of the first Digital Terrestrial Television (DTT) standard, namely DVB-T. Their main advantage is that, providing that all the transmitters are time and frequency synchronized, the same content can be delivered over the whole network occupying a single RF channel. Nevertheless, the local/regional content delivery is still one of the major drawbacks for SFNs. In this paper, Layered Division Multiplexing (LDM) is proposed as the definitive technique that will allow the seamless delivery of local contents or targeted advertisements over SFNs. LDM is a spectrum efficient non-orthogonal multiplexing technology that has been adopted in the ATSC 3.0 Physical Layer Standard as Baseline Technology, which consists on the superposition of two or more data streams of different power. In this scenario, LDM upper layer can be used to deliver TDM-ed mobile-HD and 4k-UHD services, whereas the LDM lower layer with a negative SNR threshold (dB) can reliably provide seamless local coverage/service for each SFN transmitter without coverage gaps.

INTRODUCTION

Terrestrial broadcast services delivery is based on Single Frequency Networks (SFNs) in most European countries, and most likely, it will be the future of the North American broadcasting networks. No matter the implemented terrestrial standard (DVB-T, DVB-T2, ATSC 3.0), the SFNs will enable the re-use of the same spectral resource over the entire service area provided that all transmitters are synchronized in frequency and time.

Layered Division Multiplexing (LDM) [1]-[3] is a non-orthogonal multiplexing (NOM) scheme that has recently been adopted in the ATSC 3.0 Next Generation Digital TV Standard [4]. In the literature, it has been already proved both theoretically and practically that LDM is more spectrum efficient than the classical Time Division Multiplexing (TDM) or Frequency Division Multiplexing (FDM) approaches. The main enabling technologies for this NOM technique are the strong Forward Error Correction (FEC) codes, the successive signal cancellation, and adjustable power assignations for multiplexing different data streams using different layers. None of these techniques requires major changes in the current receiver structures.

LDM FOR SFN SEAMLESS LOCAL COVERAGE

SFN networks are designed to increase the spectrum efficiency and reduce the co-channel interference, so the overall service quality is improved. Nevertheless, they are not the best approach for delivering local content in the regional areas or serving targeted individual markets. What is more, none of the existing solutions have completely addressed the problem of the the local content delivery within SFN networks. The first, and simplest solutions, were based on the classical TDM/FDM schemes [6]. The main problem of these approaches is that in order to allocate resources to the local service, the global configuration resources should be decreased in a linear basis, and as a consequence, the coverage and spectrum efficiency shrinks accordingly. As a result, this family of solutions is not very attractive for such a competitive market, where the frequency is a very scarce resource. In recent years, the use of hierarchical modulation was also proposed for the local content delivery over SFN networks, being the global content transmitted on the high priority layer of the hierarchical modulation, and the local content modulated in the low priority layer [7]. Even if it can show a better performance than the previous approach, it requires a substantial complexity increase in order to be implemented in the receiver part. Finally, the distributed MIMO-SFN centralized architecture has also been presented as a solution for providing both global and local contents within an SFN [8]. In this case, the main problem for the operators is the required investments in the infrastructure and the consequent increased complexity for the iterative cancellation stage at the receiver site. In conclusion, up to now there are no proposals that fully address all the challenges related with the seamless local service content over SFN networks.

In this work, LDM is proposed as the alternative to provide local and global contents within the same SFN network, maximizing the spectrum efficiency and minimizing the required infrastructure upgrades. In addition, it can guarantee the seamless reception of the local service, and therefore, the coverage gaps will be eliminated.

The upper layer of the LDM system can be used to broadcast TDM combined mobile HD, 4k UHD HDR, or multiple enhanced 1080p HD services to the entire regional service area, whereas the LDM lower layer can be used to deliver localized services from each SFN transmitter. The main advantage of LDM is that the regional and global services are totally decorrelated.

It must be noted that the injection level, i.e. the power difference between layers, could be dynamically arranged. A high injection level, for instance 19 dB, means that the lower layer is deep buried, and therefore, the major part of the transmission power is allocated to the upper layer service. Nevertheless, if the injected level is too close to the top layer signal, the power assigned to the local content (lower layer) is too high, which will have more impact to the top layer signal decoding. Provided the lower layer configuration is more robust than the upper one, it might be the case where the lower layer coverage could be higher than the global network-wide service. This is not very effective as the LDM receiver needs to successively receive and cancel the upper layer signal first, before decoding the lower layer. Therefore, the lower layer coverage should be smaller or equal to the upper layer coverage.

ROADMAP TO IMPLEMENTATION

One of the most important features of the presented solution is that it will be backwards compatible with current DTT standards.

The first obvious case is ATSC 3.0, where this solution can be implemented using only the already approved Baseline Technologies. Its implementation would not imply any modification to standard compliant receivers and all receivers would be able to access both upper layer SFN global contents as well as low level regional/local ones.

It is also notorious that this approach could be applied to DVB-T2 based SFNs. In this case, the local service, injected 19 dB below legacy services, synchronously at the transmitter, would impact minimally the upper layer SFN content (less than 2% in transmitted power). A DVB-T2 based signaling, for instance, requires a C/N of 14 dB for a ~30 Mbps service. Provided the second layer is overlaid (19dB below) for delivering local services, the required threshold increase for the legacy system is just about 1.5 dB. In the next section a more detailed explanation for these calculations can be found.

This solution would involve replacing the exciter at the transmission site if the injection is performed synchronously (easier decoding) or just adding a new exciter + combiner that would insert the new service asynchronously without notice to the legacy transmitted signal (more complex detection of the lower layer).

The local service insertion will be transparent for legacy receivers that would dismiss a signal, at least 19 dB below their target. Those receivers prepared to decode the lower signal –local service- would first access the SFN content, perform a cancellation and access the local contents. Apparently there would not be any regulatory implication.

INJECTION LEVEL OPTIMIZATION AND SEAMLESS LOCAL CONTENT INSERTION PERFORMANCE

The first parameters to take into account in the LDM network configuration are the data rate and service robustness configured for each of the layers depending on the targeted service. For seamless local service coverage, the SNR threshold of the lower layer signal needs to be a negative value in order to assure that there are no coverage gaps in the overlapping area, and thus, there is a seamless reception for the lower service. For a 6 MHz ATSC 3.0 system, the SNR thresholds ranging from -5 to -0.5 dB provide data rates from 1.5 to 4 Mbps. This capacity values are sufficient for reasonable quality, including a 720p HD service using HEVC encoding.

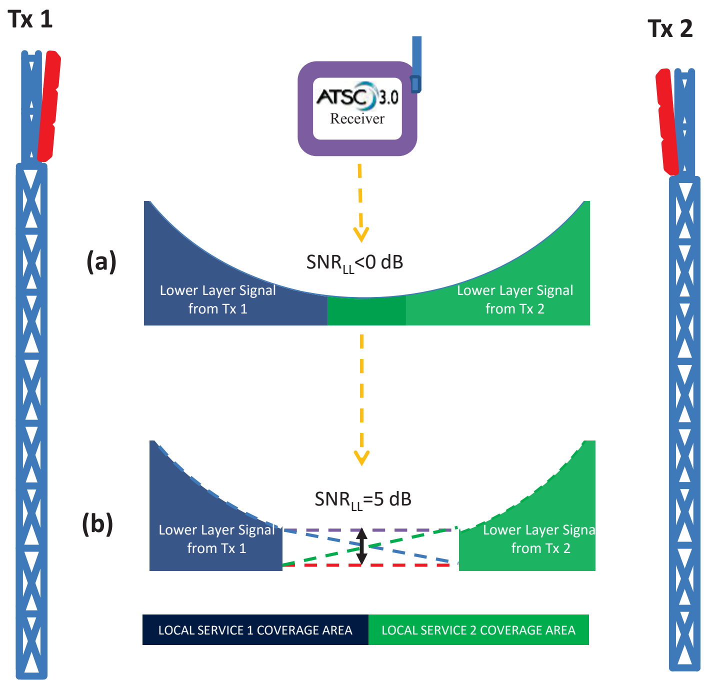

Figure 1- Local Content Using Layered Division Multiplexing

In Figure 1, the impact of the lower layer SNR threshold value onto the local service coverage between two SFN transmitters is depicted. For this analysis, it is assumed that the upper layer global content has already been decoded, and what is more, subtracted from the overall received signal without meaningful error floor. On the one hand, the upper part, Figure 2(a), depicts the situation with a negative SNR value for the local service where multiple programs can be received in the coverage overlapping area. The receiver can simply tune into the strongest signal, and as it has a very robust configuration, the co-channel interference for the other transmitted signal does not produce a coverage gap. On the other hand, Figure 2(b) shows a scenario where the SNR threshold is a positive value, e.g. 5 dB. In this case, a coverage gap remains (i.e. no local program can be received within this gap zone).

The other key parameter to analyze the LDM performance is the lower layer signal injection level, or in other words, the power resource assigned to each layer. The optimal injection level Δ to match both layers coverage footprint can be calculated as (see Eq-1):

$$\Delta = \left(\frac{S}{N}\right)_{Upper\ Layer} + 10\,log\left[1 + 10^{\left(-\left(\frac{S}{N+I}\right)_{Lower\ Layer}/_{10}\right)}\right]$$

(Eq-1)

Table 1 shows an example of a two-layer ATSC 3.0 LDM system for local service insertion. Assuming that the upper layer highest SNR is 13.9 dB (upper layer also has a TDM-ed mobile service with SNR = 3.4 dB), the lower layer SNR is -2.7 dB, and using Eq. 1, the lower layer injection level has been set up to Δ= 19 dB. In other words, it means that the lower layer only consumes 1.1% of the total transmission power, and even though, it can provide reliable local service insertion.

As a consequence, the upper layer system effective SNR can be calculated as 15.5 dB and 3.5 dB for UHD and mobile HD service, respectively. The lower layer SNR is 16.3 dB. Apart from theoretical calculations, these thresholds have been also SW simulated. The laboratory test results of these figures are 15.6, 3.6 and 16.5 dB, respectively. It should be noted that the SNR values in Table 1 are referenced to single transmitter power.

LDM Upper Layer (TDM)	Code Rate	TDM	Data Rate	SNR w/o LDM	SNR with LDM / Simulation Results
Upper Layer 256NUC 4k-UHD Upper Layer QPSK Mobile HD	8/15 11/15	75% 25%	16.4 Mbps 1.9 Mbps	13.9 dB 3.4 dB	**15.5 dB** / **15.6 dB** **3.5 dB** / **3.6 dB**
LDM Lower Layer	**Injection Level *Δ* = 19 dB below the Upper Layer**				
Lower Layer QPSK for Seamless Local Service Insertion	4/15	100%	2.7 Mbps	-2.7 dB	**16.3 dB** / **16.5 dB** SFN worst-case 0 dB Co-CH: SNR=19.6dB

Table 1- An Example of a Two-Layer ATSC 3.0 LDM System for Seamless Local Service.

For the receiver, the worst location will occur for the 0dBECHO case, when the two signals from different transmitters have equal power. In this case, for the upper layer signal, the channel can be modeled as a two-path 0dB case. For the lower layer with two different local programs, once the upper layer has been removed, it is a 0 dB co-channel interference condition. Consequently, only if the lower layer system has a negative SNR value, the local service can be seamlessly received.

For instance, in Table 1, the lower layer coding system has a SNR of -2.7 dB, with 19 dB injection level, the total noise and interference tolerance can be approximated to SNIR = 19 – 2.7 = 16.3 dB. In the case that there is 0 dB co-channel interference relative to the lower layer, i.e., 19 dB co-channel interference to the upper level, the allowed lower layer noise tolerance is SNR = 19.6 dB, meaning that there is a degradation of 3.3 dB in comparison to the no co-channel interference case. Nevertheless, it must be noted that the upper layer also requires higher SNR to deal with the SFN 0dB-path scenario, and therefore, the network is designed to have much higher SNR in these cases, offering the extra power required for the lower layer.

COVERAGE STUDY

In this section, a preliminary coverage study for the SFN LDM case is presented. In particular, Figures 2 to 4 show different coverage predictions using the transmission system parameters in Table 2.

Transmitter Name	Power (ERP)	Lower Layer Equivalent Power (ERP)	HAAT (m)	Antenna Type
Single Tx	100 kW	1260 W	356	Sector (215° beam width)
Main Tx1	8 kW	101 W	356	Sector (215° beam width)
Main Tx2	1.5 kW	19 W	185	Omni-Directional
Main Tx3	0.25 kW	3 W	375	Omni-Directional
Low Tx	1.5 kW	19 W	66	Directional (40° beam width)

Note: Receiver Antenna Height: 1.5 meters; Omni-directional; Longley-Rice F(50,90), 50% of location, 90% of time.

Table 2- Transmitter and Receiver Parameters

First of all, in Figure 2 the current single transmitter coverage (red line) and a three transmitter SFN network (black line, LDM upper layer) in Canadian national capital region (Ottawa/Gatineau) are shown. The single transmitter power is 100kW ERP, whereas the SFN transmitters' ERPs are 8kW, 1.5kW and 0.25kW, respectively. The coverage prediction rule is (50, 90); i.e., 50% of location availability and 90% time availability. At the receivers, omni-directional antennas are assumed with a height of 1.5 meter above the ground. The single transmitter and the SFN have very similar coverage, but in the SFN case, only 10% of the single transmitter power is required. In addition, the co-channel interference range is reduced, consequently, making it more spectrum-efficient.

Second, Figure 3 depicts the SFN LDM lower layer coverages (red, green and blue contours) for a negative SNR threshold of -2.7 dB. It must be noted that not only the seamless local program reception is possible, but also the decoding of multiple programs.

Finally, the coverage gaps due to a positive threshold for the local service are depicted in Figure 4.

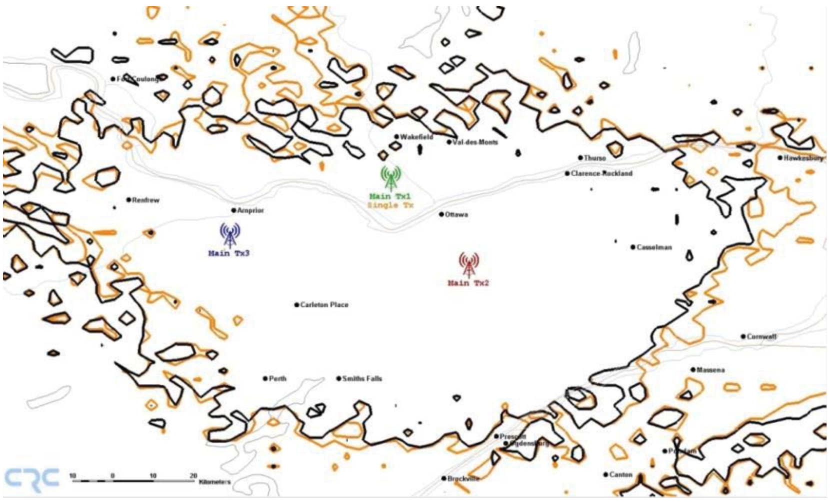

Figure 2- Single Transmitter (red line) vs. SFN (LDM upper layer black line) Coverage.

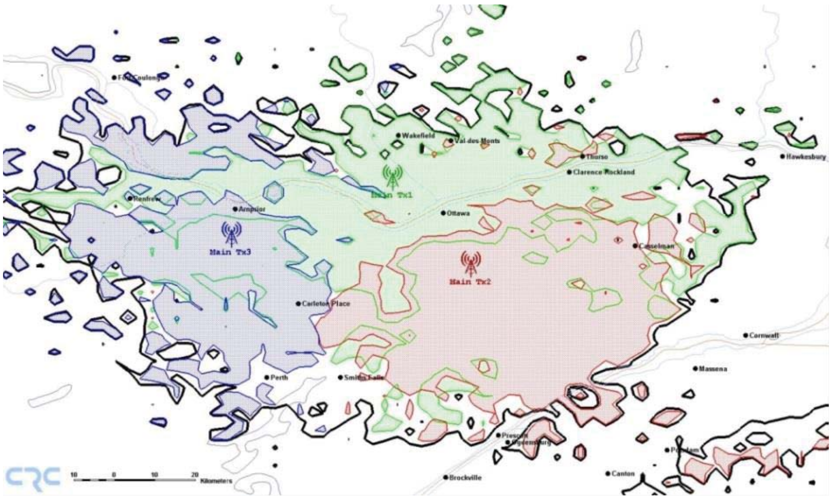

Figure 3- LDM SFN Coverage: Red, Green, Blue Contours Represent Lower Layer Local Service Coverage; Black Line Indicates Upper Layer Regional Service Coverage (lower layer coding SNR = -2.7 dB, omni-Rx antenna).

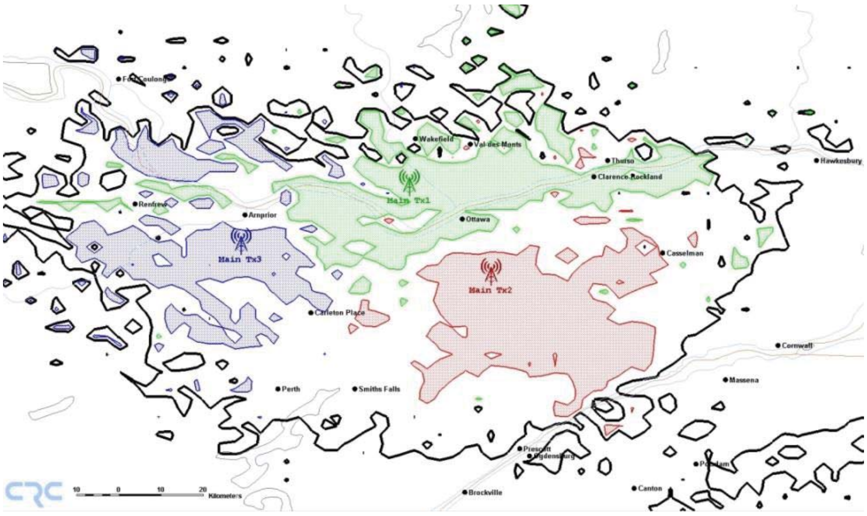

Figure 4- LDM SFN Coverage: Red, Green, Blue Contours Represent Lower Layer Local Service Coverage; Black Line Indicates Upper Layer Regional Service Coverage (lower layer coding SNR = +5.0 dB, omni-Rx antenna).

CONCLUSIONS

The LDM capability included in ATSC 3.0 can be implemented as an enabling technology to provide seamless local coverage/service, such as location targeted advertisement or local content insertion. In particular, the LDM upper layer can be used to deliver TDM-ed mobile-HD and 4k-UHD services operating in a single frequency network, whereas the LDM lower layer (with a negative SNR threshold in dB), can provide seamless local coverage/service. For this approach, the coverage gaps among SFN transmitter service areas for the local contents can be completely removed.

In addition, there is no need for additional infrastructure and a simple omni-directional receiving antenna can be used, providing the right upper and lower layers data rate requirements and SNR thresholds. The best lower layer injection level can be optimized for maximizing upper and lower layer performance and coverage. Finally, it must be noted that since the advertisement time is typically less than 20% of the program time, Non-Real Time (NRT) could be used to play-back the local content at 5 times the transmission bit rate for better (audio/video) service quality.

ACKNOWLEDGMENT

This work has been financially supported in part by the University of the Basque Country (UFI 11/30), in part by the Basque Government (IT-683) and in part by the Spanish Ministry of Economy and Competitiveness under the project 5G-NewBROs (TEC2015-66153-P). This work is supported in part by National Natural Science Foundation of China (61420106008, 61521062), 111 Project (B07022), Shanghai Key Laboratory of Digital Media Processing (STCSM12DZ2272600), and Scientific and Innovative Action Plan of Shanghai (15DZ1100101). This work was partly supported by Institute for Information & Communications Technology Promotion (IITP) grant funded by the Korean government (MSIP) [R0101-15-294, Development of Service and Transmission Technology for Convergent Realistic Broadcast].

REFERENCES

[1] L. Zhang, W. Li, Y. Wu, X. Wang, S-I Park, HM Kim, J-Y Lee, P. Angueira, and J. Montalban, “Layered Division Multiplexing: Theory and Practice,” IEEE Trans. Broadcasting, vol. 62, no. 1, Part II, March 2016.

[2] J. Montalban, I. Angulo, C. Regueiro, Y. Wu, L. Zhang, S.-I. Park, J.-Y. Lee, H. M. Kim, M. Velez, and P. Angueira, “Performance Study of Layered Division Multiplexing Based on SDR Platform,” *IEEE Trans. Broadcasting,* vol. 61, no. 3, pp.436-444, Sept. 2015.

[3] L. Zhang, W. Li, Y. Wu, Z. Hong, K. Salehian, X. Wang, P. Angueira, J. Montalban, M. Velez, S.-I. Park, H.M. Kim, and J.-Y. Lee, "Performance Characterization and Optimization of Mobile Service Delivery in LDM-Based Next Generation DTV Systems,” *IEEE Trans. Broadcasting,* vol. 61, no. 4, pp.557--570, Dec. 2015.

[4] “A/322 ATSC Candidate Standard – Physical Layer Protocol,” Doc. S32-230r21, 28 September 2015. http://atsc.org/wp-content/uploads/2015/10/S32-230r21-PHY-STD-CS.pdf

[5] G. May and P. Unger, "A New Approach for Transmitting Local Content Within Digital Single Frequency Broadcast Networks," in *IEEE Transactions on Broadcasting*, vol. 53, no. 4, pp. 732-737, Dec. 2007.

[6] M. R. Chari *et al*., "FLO Physical Layer: An Overview," in *IEEE Transactions on Broadcasting*, vol. 53, no. 1, pp. 145-160, March 2007.

[7] H. Jiang, P. A. Wilford and S. A. Wilkus, "Providing Local Content in a Hybrid Single Frequency Network Using Hierarchical Modulation," in *IEEE Transactions on Broadcasting*, vol. 56, no. 4, pp. 532-540, Dec. 2010.

[8] Jeon, H. J. Ryu, I. Kyung, and M.-S. Kim, “Cooperative local area contents transmission within a single frequency broadcast network,” in Proc. 58th IEEE Annu. Broadcast Symp. (ABS), Alexandria, VA, USA, Oct. 2008.