Enhanced TV Delivery with eMBMS: Coverage Evaluation for Roof-Top Reception

Jordi Joan Gimenez, Peter Renka
Institut für Rundfunktechnik GmbH
Munich, Germany
{jordi.gimenez,renka}@irt.de

Simon Elliott, David Vargas
British Broadcasting Corporation,
London, United Kingdom
{simon.elliott,david.vargas}@bbc.co.uk

David Gomez-Barquero
Universitat Politècnica de València,
Valencia, Spain
dagobar@iteam.upv.es

***Abstract*— 3GPP Release 14 has further improved eMBMS to enable the provision of television services according to requirements commonly found in the broadcasting industry. The improvements include several radio interface enhancements such as the support for larger inter-site distances in SFN deployments, the introduction of a dedicated eMBMS carrier with 100% broadcast resource allocation complete with a new, lower overhead subframe, stripping out the unicast control region. Studied in this paper are the main innovations introduced in Release 14 with respect to SFN coverage performance. Analysis has been carried out for low power low tower (LPLT) i.e. cellular networks and high power high tower (HPHT) networks typical in broadcasting today. Special focus is given to providing reception to fixed roof-top antennas, broadcasters' main coverage mode.**

Keywords*— eMBMS, HPHT, LPLT, cyclic prefix, cell acquisition subframe, SFN.

I. INTRODUCTION

3GPP specifications are not static – they evolve rapidly over time and are issued periodically (around every 18 months) in the form of Releases, with each subsequent Release introducing new features and characteristics to meet requirements set by industry. The most recent 4G standard is LTE-Advanced Pro Release 14 [1]. In this release several enhancements were made to eMBMS (enhanced Multimedia Broadcast Multicast Service) in order to make it more suitable for delivering TV services [2]. Improvements were made to a number of areas including the system architecture as well as the service and radio layers. For example, the interface through which broadcasters could inject their content into the network, to be transported over eMBMS, was standardised. Service layer components, similar to those in traditional TV delivery platforms were added, and improvements were made in the radio access network in order to increase efficiency and provide wide area coverage. The latter – achieving wide area coverage with Release 14 eMBMS – is the focus of this paper.

Since its introduction in LTE Release 9, eMBMS has generally been associated with SFN (Single Frequency Network) operation in cellular networks where clusters of several base stations using the same frequency, or carrier, are time- and content-synchronized. The same time-frequency resource can, in this way, be used to simultaneously deliver popular content to multiple recipients, thus efficiently using the network. In 3GPP terminology these networks are known as Multicast Broadcast SFN (MBSFN).

A cyclic extension of the original OFDM symbol, known as the cyclic prefix (CP), is appended to the beginning of the OFDM symbol. Suitable positioning of the FFT window avoids inter-symbol interference in SFNs provided that all signals are received with maximum relative delays up to, but not more than the CP duration. Furthermore, signals arriving in this range contribute constructively to the received signal. An OFDM signal with sufficiently long CP can, in this way, withstand the 'artificial' multipath, or echoes, generated by the otherwise identical signals from the transmitters in the SFN [3].

Release 14 eMBMS also enables a CP of 33.33 μs with the introduction of corresponding signalling to support maximum inter-site distance (ISD) of 10 km. Prior to this release, the maximum CP was 16.67 μs, restricting the maximum ISD to 5 km. i.e. eMBMS was intended for use in LPLT or cellular networks. The introduction of the significantly longer (200 μs) CP and 1 ms OFDM symbol duration in Release 14 may now permit ISDs of up to 60 km [4].

Combined with the support for 100% eMBMS resource allocation, including a dedicated broadcast-only carrier with self-contained system information, synchronization and signalling, these enhancements raise the potential of a single standard extending TV reception to both TV-sets and smartphones.

Now that the standard is complete, it is time for the characteristics of the new system to be evaluated. One of the key performance indicators (KPIs) for technologies in the context of broadcasting is the coverage that they achieve, as this defines the spectral efficiency, receivable with a certain probability, within a given geographical area [5]. In relation to eMBMS and the technical improvement at the radio layer in Release 14, this KPI is the main subject of this paper.

Section II of this paper describes the main changes made in Release 14 that are relevant to the coverage of eMBMS while coverage simulations in Section III show how eMBMS may perform in a variety of LPLT and HPHT networks of various ISDs for fixed roof-top reception. These are then complemented by a practical example based on the United Kingdom's DTT network in order to appreciate how eMBMS may perform in practice taking into account the irregularities of the network and reception environment. Finally, several conclusions are drawn followed by suggestions of potential future enhancements and recommendations that may be of interest for the future development of broadcasting systems in the context of 5G [6].

II. OFDM Parameters for SFN Operation in eMBMS

A. *Numerology and framing options in Release 14*

LTE Release 14 defines a number of different numerologies. These are summarised in Table I where it can be seen that three sub-carrier spacings (Δ_f), combine with four different CP durations (T_{CP}), creating four different numerologies with the useful OFDM symbol durations (T_U) as shown. The normal CP (4.7 µs) and 15 kHz sub-carrier spacing is not defined for MBSFN subframes. Note that, in order to completely fill the slot, the first OFDM symbol of the normal CP has a longer 5.2 µs duration (cf. 4.7 µs otherwise).

MBSFN operation enables three extended CP options. A CP of 16.67 µs duration with 15 kHz Δ_f is available, as is a longer 33.3 µs CP with Δ_f of 7.5 kHz. By decreasing Δ_f to 1.25 kHz, Release 14 has introduced a new extended 200 µs CP [7]. In all cases the overhead due to the CP is 20%. As shown in Table I, the maximum ISDs for the two short CPs are 5 km and 10 km, which are only practical in LPLT networks. The new CP extends the ISD up to 60 km which may also be used in HPHT deployments.

TABLE I. Numerologies in eMBMS Release 14

	Δ_f (kHz)	Subcarr. per Resource Block	OFDM symbols per subframe	T_{CP} (µs)	T_U (µs)	ISD (km)
Normal	15	12	14	4.7/5.2	66.7	1.4
Extended	15		12	16.7	66.7	5
	7.5	24	6	33.3	133.3	10
	1.25	144	1	200	800	60

The selection of particular OFDM parameters has an impact on the structure of the frames. Each frame (10 ms) is composed of 10 subframes (1 ms) comprising 2 slots (0.5 ms). In the 200 µs CP variant the OFDM symbol occupies the entire duration of a sub-frame. In this case, the unicast control region in MBSFN subframes has been eliminated.

B. *Reference signals*

The eMBMS modes have an associated set of reference signal patterns that are denser in the frequency direction compared with the standard unicast patterns. These help the receiver correctly equalise the channel in the presence of 'artificial' echoes with long delays generated by distant transmitters in the SFN. Each cell belonging to an MBSFN area transmits the same MBSFN reference signal pattern at precisely the same time-frequency position.

As shown in Figure 1, for the 15 kHz sub-carrier spacing variants, known reference symbols are inserted in every other sub-carrier in the 3rd, 7th and 11th OFDM symbol of each sub-frame, with a single sub-carrier offset in the 7th OFDM symbol. In the 7.5 kHz sub-carrier spacing variant, one reference signal is inserted in every four sub-carriers in the 2nd, 4th and 6th symbols of each sub-frame, as shown. In the 1.25 kHz variant, one in six sub-carriers is occupied by reference symbols, also with an offset on odd vs even sub-frames, as shown.

With respect to multipath, or echoes – either artificial or natural – the frequency spacing between pilots determines the length of delay up to which the channel may be correctly equalised when using time-frequency interpolation. Delays up to the duration of the equalization interval (EI) may be tolerated.

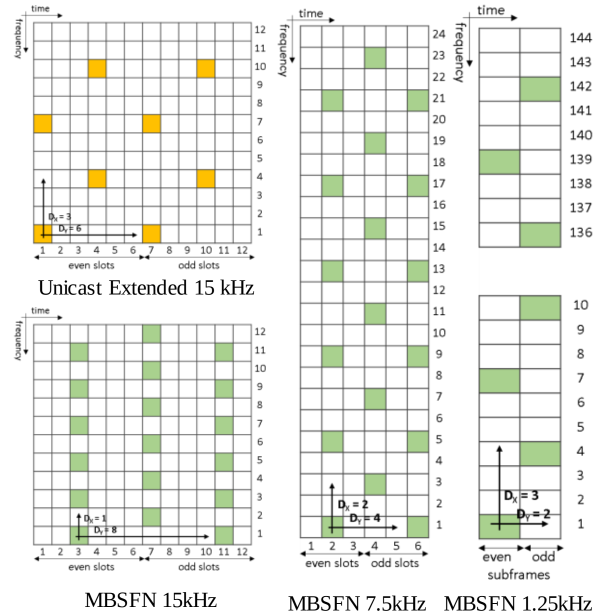

Fig. 1. Reference signals for MBSFN subframes and unicast subframes with different numerologies.

The EI is calculated assuming that the receiver is able to perform time and frequency interpolation. A factor of 57/64 is considered to account for realistic receiver implementation [8]. According to the frequency separation between reference signals D_x, the EI for MBSFN subframes is 59.3 µs for Δ_f 15 kHz and 7.5 kHz and 237.5 µs for Δ_f 1.25 kHz.

C. *Cell Acquisition Subframe*

Previous releases of LTE eMBMS defined MBSFN frames with up to 60% broadcast resource allocation (6 out of 10 subframes per frame). The remaining 40% was allocated to unicast traffic and signalling. Release 14 enables a dedicated broadcast carrier with with almost 100% broadcast allocation. In this mode the signalling required for synchronization, acquisition and service discovery has been minimized and encapsulated in the Cell Acquisition Subframe (CAS). It is transmitted once every 40 subframes, equating to an overhead of 2.5%.

The CAS comprises the following signals and channels: PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal), CRS (Cell-Specific Reference Signal), PBCH (Physical Broadcast Channel), PDCCH (Physical Downlink Control Channel) and PDSCH (Physical Downlink Shared Channel). The correct reception of these enables access to the PMCH (Physical Multicast Channel) which conveys the MBSFN subframes containing the data. LTE system information (SI) is generally carried on the PDSCH. Access to this information is gained in conjunction with a downlink control information (DCI) message transmitted on the PDCCH that indicates the format and resource allocation of the PDSCH

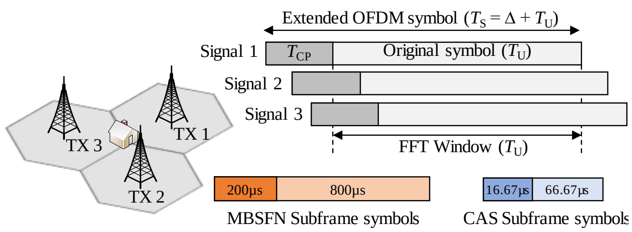

Fig. 2. Single Frequency Network (SFN) with 3 transmitters. Reception of contributions and role of the cyclic prefix. MBSFN subframes are designed to provide wide area coverage. CAS subframes with legacy numerology may suffer from a certain degree of interference.

transmission. Some initial system information is conveyed in the master information block (MIB), which is carried on the PBCH. The PSS and SSS are used for signal acquisition and the CRS for channel estimation [9].

The CAS is transmitted using the 15 kHz unicast numerology with the ability to use either the 4.7 µs or 16.67 µs CPs. In practice this means that the CAS can tolerate short or moderate signal delays whereas the MBSFN subframes would tolerate larger delays.

Figure 2 shows the structure of the OFDM symbols employed in the CAS and MBSFN subframes. As the CAS is based on the unicast subframe structure the EI is calculate to be 19.8 µs.

As the correct reception of the CAS is critical for the subsequent reception of the MBSFN subframes the different channels within the CAS have purposefully been made robust – they can generally be demodulated at low or negative SINR (Signal-to-Interference plus Noise) thresholds. The reception of the CAS has been evaluated in 3GPP [10][11][12] in which it is found that the required SNRs for 1% PBCH BLER point are -6.6 dB and -4.8 dB for ETU1 and EPA1 channels respectively. The required SNRs for 1% PDCCH (DCI 1A) BLER point are -5.0 dB and -3.3 dB for ETU1 and EPA1 channels respectively. The required SNRs for 1% PDSCH (TBS 1384 bits) BLER point are -5.6 dB and -4.1 dB for ETU1 and EPA1 channels respectively.

However, these results are for MIMO (multiple-input multiple-output). No results were made available for SISO (single-input single-output) – the only possible antenna configuration for MBSFN transmission. The channel models employed in the evaluation are also not appropriate for fixed roof-top reception. Note also that, although the standard does not state if the PSS/SSS (i.e the PCI - Physical Cell Identifier) can be the same for all sites, it is assumed that is still possible to implement PCI planning strategies to minimize interference. For the evaluation in this paper we assume that the reception of the CAS is conditioned by the value -3.3 dB as a reference SNR for coverage estimation.

III. COVERAGE ANALYSIS OF eMBMS IN LTE RELEASE 14

The following coverage analysis of Release 14 eMBMS focuses on the 200 µs extended CP numerology and the performance of the CAS with unicast numerology.

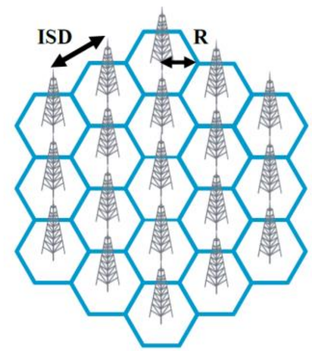

Fig. 3. Reference network layout showing 2 rings around the central cell of interest.

A. *Network layout and methodology*

Wide area SFNs have been modelled using the network layout shown in Figure 3 extended to include five rings of sites around the central transmitter. As illustrated, each cell contains a transmitter at its centre. The coverage, incorporating the effects of SFN self-interference, has been computed at the worst performing point of the central hexagon.

In the LPLT networks the effective radiated power (ERP) was set to 40 W at an effective antenna height of 30 m while 50 kW and 250 m were used for the HPHT network.

Table II sets out the receiving environment parameters used in the simulations; all values are in-line with [8]. ITU-R P.1546-5 has been used to calculate the mean signal strengths of the wanted and interfering signals in 100m x 100m 'pixels' comprising the coverage area. Within a pixel these signals vary from one location to another according to a log-normal distribution with standard deviation of 5.5dB, and have thus been modelled as random variables. The Schwartz and Yeh method has been used to calculate the combined wanted and interfering signal powers so that the probability of reception at any point within the pixel can be determined. Coverage quality is then expressed as the percentage of locations exceeding a given SINR threshold within a pixel for 99% of the time. Common coverage thresholds used in broadcast network planning are: 70 and 95% locations.

TABLE II. RECEPTION AND PROPAGATION PARAMETERS

Parameter	Fixed Roof-Top Reception
Receiving Antenna Height	10 m
Receiver Noise Figure	6 dB
Rx Antenna Pattern	ITU-R BT.419
Rx Antenna Gain	13.15 dBi
Antenna Cable Loss	4 dB
Implementation Margin	1 dB
Noise Bandwidth	4.5 MHz
Frequency	700 MHz
Propagation Model	ITU-R P.1546-5 over land
Wanted Signal Time Value	50% time
Interfering Signal Time Value	1% time
Location Variation	5.5dB (log-normal distribution)
Signal Summation	Schwartz & Yeh power sum
Pixel size	100m x 100m

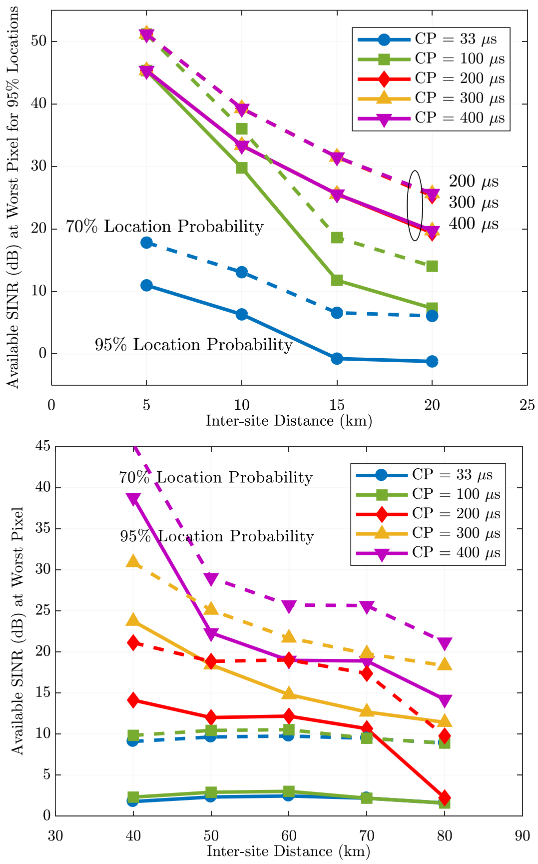

Fig. 4. Available SINR at the worst pixel of the LPLT and HPHT networks as a function of the ISD and different CP duration (SFN).

B. MBSFN coverage performance for fixed roof-top reception

A generic analysis of the coverage capabilities of eMBMS for fixed roof-top reception has been conducted based on hexagonal networks. The SFN self-interference has been evaluated as a function of ISD for various different CP lengths (33, 100, 200, 300 and 400 µs) where the two latter CPs have been hypothecated in order to determine whether there would be any benefit in further extending the CP. For these two modes the OFDM symbol period has been extended accordingly so that the CP always represents ¼ of the symbol duration – in line with the standardised eMBMS modes. The achievable SINR, in the worst pixel of the central hexagon in the network was then computed for reception qualities of 70% and 95% locations.

Figure 4 presents the results for LPLT (top) and HPHT (bottom) networks. It was found that for all the LPLT ISDs studied, the 200 µs CP would be sufficiently long. Extending it further would provide no additional benefit against SFN self-interference – the achievable SINR would not increase. Conversely it can be seen that the 200 µs CP significantly improves the SINR for all the LPLT ISDs studied compared with the 33 µs option while a 100 µs variant may be a good addition for networks with ISDs of 5 to 10km.

For HPHT networks, it can be seen that the 200 µs CP would significantly improve the SINR compared with the 33 µs variant. However, for ISDs greater than 70 km – i.e. ISDs

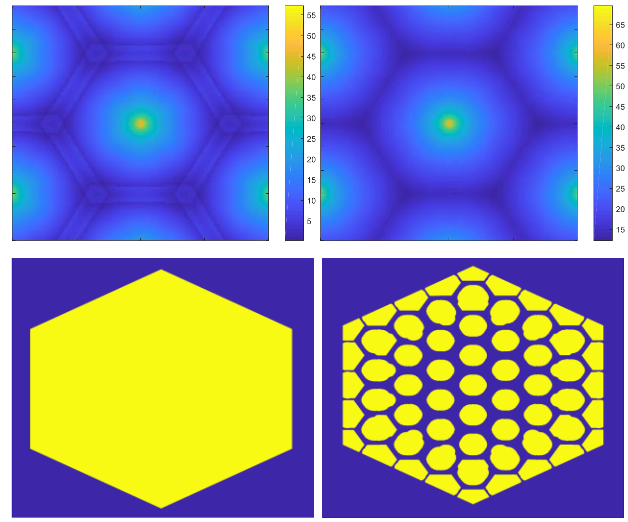

Fig. 5. Available SINR for the CAS (top-left) and MBSFN (top-right) subframes. Receiver locations with SINR ≥ -3.3 dB for the CAS (bottom-left), and SINR ≥ 20 dB for the MBSFN (bottom-right).

typical of existing DTT networks – the introduction of even longer CPs would further improve the coverage of the system.

According to the results, wide area coverage in existing DTT networks – where ISDs of 60km or more are common - may be limited to modes with SINR thresholds below 12-13 dB for 95% coverage availability, or below 19 dB for 70% coverage availability.

C. Coverage of the Cell Acquisition Subframe

The coverage of the CAS operating as an SFN has been calculated for the 16.67 µs CP (66.7 µs T_U and 19.8 µs EI). For comparison, the MBSFN coverage for the 200 µs CP, (800 µs T_U and 237.5 µs EI) has also been computed. In both cases a HPHT network with 60 km ISD has been used.

Figure 5 (top) shows the available SINR in and around the central cell. It can be seen that the different numerologies for the CAS and MBSFN subframes generate distinctly different coverage with the CAS being more interference limited than the MBSFN. Therefore, in order to determine the actual coverage of the system we need to jointly consider both the CAS and MBSFN subframe types. The bottom half of the figure shows in yellow the receiver locations offering SINR values above -3.3 dB (for CAS) and 20 dB (for MBSFN). In this case, the coverage of the data subframes is not limited by the reception of the CAS.

The coverage of eMBMS in a national SFN is now assessed in the UK DTT network in order see what may happen in a more practical setting.

In this example the UK Prediction Model (UKPM) was used – a prediction model jointly developed by ITC, BBC, Crown Castle and NTL for planning DTT services in the UK [13]. All 1,100+ UK DTT transmitters were modelled with the eMBMS parameters shown in Table III. All other physical characteristics of the network, such as antenna patterns, ERPs, transmitter locations and antenna heights were otherwise unchanged. The predicted coverage is shown in Table III where the CAS & MBSFN row shows where these two signals would be available from the same site. A target SINR of at least 20dB was used for the MBSFN as more than 98.5% of the UK population may receive this level today.

It is clear from Table III that the 200 µs CP would be too short to achieve near-universal coverage with a national SFN. Although this result is somewhat different to the hexagonal network simulations, it may be explained by observing that practical networks are much less regular. For example, they contain real terrain and ISDs of various lengths, some greater than 60 km. Sea paths over convex sections of coast also lead to higher interference than is found in the land based regular hexagon networks. A longer CP, in the order of 400 µs, may therefore be reasonably considered.

TABLE III. UKPM RESULTS

Signal	Percentage of UK Households at Percentage Locations			
	MBSFN: CP 200 µs, Ts 1 ms, EI 267 µs		MBSFN: CP 400 µs, Ts 4 ms, EI 1.2 ms	
	70%	95%	70%	95%
CAS (-3 dB)	100	98.6	100	98.6
MBSFN (20 dB)	86.5	67.4	99.2	96.2
CAS & MBSFN	86.5	66.5	98.9	93.2

Additionally, the CAS may not be robust enough at -3dB for networks designed with high location percentage targets (i.e. 95%) as it may begin to limit the coverage of the MBSFN. Note also that the pixels where CAS and/or MBSFN are available is found to be not co-located in some cases. Further work should be undertaken in order to confirm the performance of the CAS.

Figure 5 shows an example of the coverage map of the UK where only the populated pixels are calculated for a target location percentage of 95%. The green pixels represent pixels where the reception of the CAS and MBSFN are available. Red pixels represent when the CAS is available but the MBSFN is not. Blue pixels denote the unavailability of both CAS and MBSFN.

IV. CONCLUSIONS

This paper presents an initial evaluation of the coverage offered by eMBMS in LTE Release 14 in both hexagonal and real networks considering roof-top reception, as the traditional target of terrestrial broadcasting networks. The relevant topics under analysis are the extended CP of 200 µs CP and the new framing including a cell acquisition subframe based on legacy numerology.

Although a 200 µs CP would theoretically be sufficient to cope with SFN self-interference in HPHT topologies with ISDs up to 60 km, in practice interference from sites more distant in the network must be taken into account. Doing so has shown that longer CPs (e.g. 400 µs) would improve the performance of LTE in these networks, and could be considered in further eMBMS revisions., especially in the context of 5G.

In LPLT topologies, the extension of the CP may not be necessary since 200 µs CP results sufficient to cope with SFN self-interference.

The use of the CAS should be further studied since the existing results in 3GPP do not permit the correct assessment of the coverage. With the assumptions taken in this paper it is shown that the misalignment of the numerologies between MBSFN and CAS subframes may prevent the proper deployment of SFN networks. Coverage may become limited by the CAS in locations where the MBSFN subframes could potentially be received. The possibility of sending the initial signalling in SFN mode providing similar SFN performance as the data subframe can be of interest in 5G.

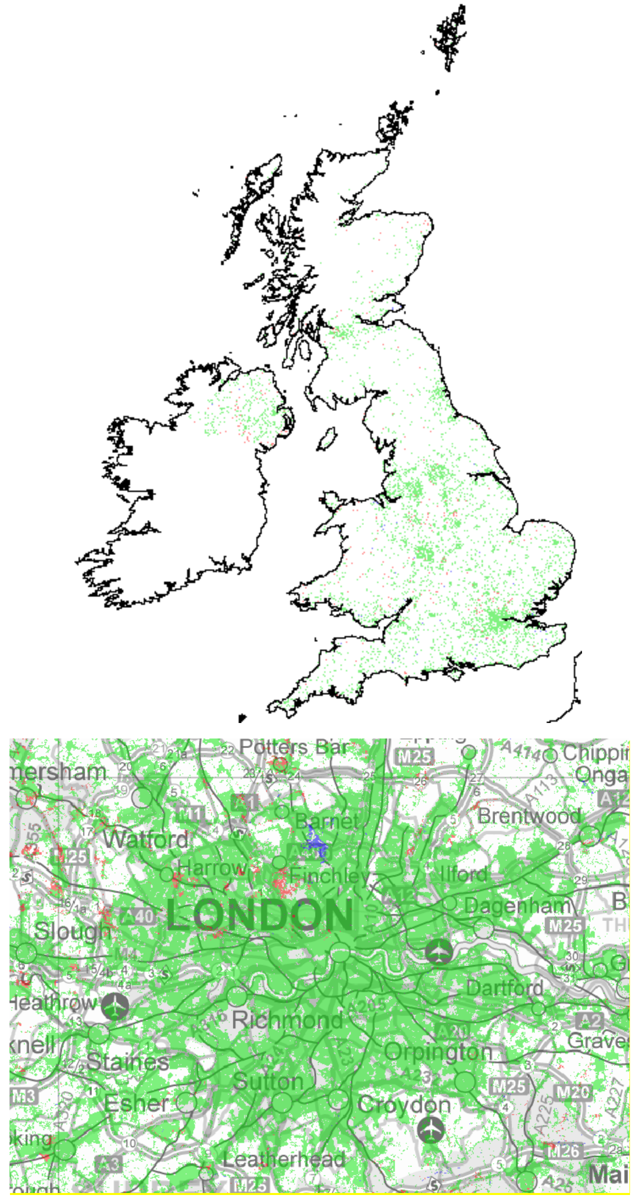

Fig. 5. Populated pixels in UK where reception of either CAS-only (red), MBSFN-only (blue) or both (green) is possible.

ACKNOWLEDGMENT

This work was partially supported by the European Commission under the 5G-PPP project 5G-Xcast (H2020-ICT-2016-2 call, grant number 761498). The views expressed in this contribution are those of the authors and do not necessarily represent those expressed in the 5G-XCast project.

REFERENCES

[1] C. Hoymann *et al*., "LTE release 14 outlook," in *IEEE Communications Magazine*, vol. 54, no. 6, pp. 44-49, June 2016.

[2] 3GPP, "3GPP enhancement for TV service (Release 14); Tech. Rep. 22.816, v.14.1.0, March 2016.

[3] R. Brugger, D. Hemingway, "OFDM Receivers – Impact on coverage of inter-symbol interference and FFT window positioning", EBU Technical Review 295, July 2003.

[4] L. Zhang, Y. Wu, G. K. Walker, W. Li, K. Salehian and A. Florea, "Improving LTE eMBMS With Extended OFDM Parameters and Layered-Division-Multiplexing," in IEEE Transactions on Broadcasting, vol. 63, no. 1, pp. 32-47, March 2017.

[5] D. Vargas and D. Mi, Eds., "LTE-Advanced Pro Broadcast Radio Access Network Benchmark," Deliverable D3.1, 5G-PPP 5G-Xcast project, Nov. 2017.

[6] D. Gomez-Barquero, D. Navratil, S. Appleby and M. Stagg, "Point-to-Multipoint Communication Enablers for the Fifth-Generation of Wireless Systems", *IEEE Communications Standards Magazine*, vol. 2, no. 1, March 2018.

[7] A. Awada, M. Säily and L. Kuru, "Design and performance impact of long cyclic prefixes for eMBMS in LTE networks," 2016 IEEE Wireless Communications and Networking Conference, Doha, 2016, pp. 1-7.

[8] EBU, "Simulation Parameters for Theoretical LTE eMBMS Network Studies", Tech. Rep 034.

[9] Cox, C. (2014). Cell Acquisition. In An Introduction to LTE, C. Cox (Ed.).

[10] 3GPP, R1-1610312, "Considerations on PBCH coverage enhancement"

[11] 3GPP, R1-1611609, "Initial acquisition and system information for eMBMS for 100% MBSFN subframe allocation"

[12] 3GPP, R1-1611493, "Performance results for cell acquisition"

[13] P. G. Brown, K. T. Tsioumparakis, M. Jordan, A. Chong, "UK Planning Model for Digital Terrestrial Television Coverage, " BBC Research & Development, White Paper WHP 048, Sept. 2002.