Spectrum Requirements for TV Broadcast Services using Cellular Transmitters

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Abstract—Wide-spread provisioning of TV services has strongly shaped the cultural development since the last century; terrestrial radio broadcast transmission has been the original form of TV distribution. Although the majority of TV reception is today based on alternative distribution means, like cable or satellite, TV broadcast enjoys still a significant amount of allocated terrestrial spectrum (~300 MHz). However, it has been identified that TV broadcast does not efficiently use its allocated spectrum. At the same time, other spectrum users like mobile communication systems experience a tremendous growth and demand for spectrum. The scarcity of radio spectrum has led the US FCC rule that additional 500 MHz of spectrum are to be identified for mobile broadband systems in the next decade – out of which 120 MHz are to come from the TV band in the next 5 years. In this paper we identify an alternative transmission architecture for TV distribution based on cellular LTE MBMS, with densely placed low-power transmitters that transmit in a synchronized single frequency network. It is demonstrated that in this way a full frequency reuse at all sites is possible, in contrast to the large reuse distances in high-power high-tower TV transmission. As a result, we show that it is possible to support TV services with 84 MHz of spectrum via LTE MBMS, in contrast to the 300 MHz used by today’s ATSC TV broadcast system. This approach can be realized in a cost-effective manner by re-using existing mobile network infrastructure and we also show that the total radiated power can be decreased.

Keywords—spectrum; MBMS; LTE; ATSC

I. INTRODUCTION

TV broadcast services have strongly shaped the social and cultural development during the last century and are considered an important cultural good. The traditional means of providing TV programs to the households is by means of terrestrial broadcast distribution. Today terrestrial broadcast distribution is still used by approx. 10% of households in the USA as their sole means of receiving television. The spectrum bands that are allocated to TV broadcast transmission in the US – after the switchover from analog to digital transmission – are 54-72 MHz, 76-88 MHz, 174-216 MHz and 470-698 MHz. This sums up to a total of 300 MHz of TV broadcast spectrum. The majority of households however receive TV programs today via cable, satellite, and recently also via Internet connections.

Another technology that has greatly shaped society during the last two decades is mobile communication. Mobile telephony is rapidly growing into a variety of personal multimedia services and mobile Internet services that are possible with a mobile broadband subscription. In the future, machine-based communications are expected to add a panoply of use cases for mobile wireless networks, such as e-Health, transportation, and the Smart Grid. The success of mobile and wireless communications has lead many administrations to identify a need to increase the amount of spectrum that is allocated to mobile communication systems. The US national broadband plan [3] has expressed the target to provide additional 500 MHz of spectrum to mobile communication systems in the next 10 years, of which 300 MHz shall already be provided within the next 5 years. At least 120 MHz of this spectrum are supposed to come from the spectrum band that is currently allocated to TV services. The spectrum is mainly expected to be freed by a combination of efficiency measures, e.g. channel repacking, channel sharing, better network architectures, including cellular-like architectures. In the process, there is an implication that the continued delivery of broadcast television will not be compromised.

This paper investigates what amount of spectrum is required to provide today’s TV offerings using an alternative network deployment with a cellular-like architecture to provide the TV service with better spectrum utilization. We consider the Multimedia Broadcast/Multicast Service (MBMS) of the 3GPP LTE radio technology [5] to provide the TV broadcast transmission. We examine the amount of TV spectrum that can be reallocated to mobile broadband communications without compromising the availability and quality of TV broadcast reception. We also make a rough comparison of the total radiated power required by the two network deployment options. The choice of LTE as TV broadcast technology in this paper is only one option within a number of alternative TV transmission methods. The use of LTE can be motivated for terrestrial and mobile TV delivery as in Section II. Section III describes the use of MBMS, while the scenarios and methodology of the contribution in this paper appear in Section...
IV. Section V provides results of required spectrum corresponding to 4 exemplary TV markets in the United States. Section VI estimates the total radiated power, as a basis for future comparison of energy efficiency between the network deployments.

II. MOTIVATION FOR A NEW BROADCAST SERVICE

A. Inefficient use of spectrum

TV transmission towers for metropolitan areas can have transmitter EIRP levels of more than 1000 kW that are radiated from a height of over 200 m above average terrain. The transmitters are designed to cover a large geographic area for TV distribution. The required performance of TV service decoding is 18 dB SNR [4], for which a TV signal of -83 dBm is required at the TV receiver [10]. This leads to TV service ranges of around -80 to 100 km around a TV transmitter. At the same time, the high power levels and the transmitter heights cause strong interference in areas far beyond the TV service area. Consequently, a channel can only be reused again by another TV transmitter after significant distance far beyond the intended coverage contour. The minimum DTV station co-channel separation requirement is 224 km (depending on Zone in the Country) [1]. Considering a coverage radius per transmitter of 80 km this reuse distance in a regular hexagonal grid of omnidirectional transmitters leads to a frequency reuse factor of about 3 in the minimum, in contrast to a reuse factor of unity that are common in modern cellular communication systems. This means that the total amount of channels required for a nation-wide coverage of one TV channel is actually $X^3 \times 6$ MHz, where $X=3$ describes the overhead of spectral reuse.

B. Lack of an attractive mobile TV standard

The rapid adoption of smartphones, and the expected increase in adoption of mobile devices such as e-books and tablets is expected to create a sea change in the way mobile data is consumed. The mobile industry is interested in a convergence of all means of information consumption while the end-user is on the move. As it stands, it is expected that the mobile phone will be used to access a significant amount of video content from the Internet. As a part of this convergence, it is therefore reasonable to expect that every personal device with capabilities equivalent to and exceeding a modern smartphone will be able to provide access to TV in addition to its capability to access Internet video. Furthermore, the user experience will be greatly improved with the provision of a return channel to the network, allowing operators and broadcasters to benefit from knowledge of user behaviour, and for advertisers to gain direct access to viewers. Lastly, it is desirable that the signal format that is received by a mobile device be compatible with the signal format used predominantly for broadband access.

These reasons make LTE especially suitable for a broadcast service, beyond what has been possible with other attempts in the space such as ATSC-M/H, DVB-H or Media-FLO, which are the currently available alternatives capable of offering access to mobile TV. A further benefit is that LTE network infrastructures are currently being rolled out by several mobile network operators. A reuse of deployed infrastructure can be envisioned which enables a cost-effective transition into a novel TV broadcast network deployment.

III. LTE MULTIMEDIA BROADCAST AND MULTICAST SERVICE

A broadcast mode for mobile broadband transmission has been standardized for the WCDMA based radio access standard in 3GPP Release 6 as part of the multimedia MBMS. This has been further enhanced in Release 7 and Release 8 [6]. Here, we focus on the LTE radio access standard, for which MBMS support has been introduced in 3GPP Release 9 [7]. It is designed for reception by mobile and handheld devices but supports signal reception equally well for fixed receivers (e.g. with rooftop antennas). MBMS based on WCDMA has been included in the ITU-R recommendation BT.1833 on broadcasting of multimedia and data applications for mobile reception by handheld receivers [8]. The enhanced MBMS of Release 7-9 based on WCDMA and LTE has also been proposed to ITU-R as a candidate radio technology for a new ITU-R recommendation BT. [DMB2NDGEN] on the second generation of broadcast systems of multimedia and data applications for mobile reception by handheld receivers [9]. An overview of the MBMS architecture is provided in Annex A.

MBMS enables synchronized transmission between multiple transmitters in the form of single frequency network (MBSFN) operation. In this way, identical signals are being broadcast by multiple transmitters synchronously and do not mutually interfere with each other – they amplify each other and thus improve the overall signal quality. Another advantage of SFN operation is that it allows a direct frequency reuse (i.e. reuse factor 1) in all broadcast transmitters providing the same signal. Thereby it can be avoided that large amounts of spectrum are blocked in neighboring regions.

If in contrast, different signals are sent out by different transmitters these can of course interfere if they are transmitted from sites that are too close to each others. Such transmitters typically belong to different MBSFN areas and must be separated by a frequency reuse distance. An MBSFN area therefore needs to be surrounded by a guard area where transmission of different signals on the same channel is prohibited. Due to the small distance between MBMS sites using cellular infrastructure, also the reuse distance can be made much smaller than that for a traditional TV transmitter. A cellular architecture also allows greater control over the availability of coverage in populated areas, thus minimizing the size of the guard areas. Typical reuse distances for cellular architectures are only a few times the inter-site-distance. Furthermore, MBMS supports MBSFN area specific reference symbols so that an advanced receiver can estimate the channels to the wanted and interfering MBSFN transmitters [21]. This can be exploited for interference cancellation algorithms in the receiver.

The LTE MBSFN is similar to the Distributed Transmission System (DTS) of ATSC in radiating the same signals over a covered area with multiple transmitters. On the physical layer, while ATSC uses a single carrier transmission, LTE uses multi-carrier transmission based on Orthogonal
Frequency Division Multiplexing (OFDM). The long data symbol duration in OFDM helps mitigate inter-symbol-interference (ISI) caused by delayed signals from distributed remote co-channel interferers. OFDM in LTE furthermore uses a guard interval. Delayed signals arriving within the guard interval after the first signal to which the receiver is synchronized do not cause ISI nor inter-carrier-interference (ICI) between the OFDM sub-carriers. The use of OFDM with a guard interval enables a very simple receiver design. In contrast, DTS-ATSC receivers have to apply time domain equalization of the very high delay spread introduced by the DTS multi-site transmission. Delay spread is particularly large for a high distance between transmitters. In addition to the OFDM-specific ISI immunity, the higher site density of a cellular infrastructure that is typically used for MBMS leads to reduced delay spread compared to the low transmitter density of ATSC infrastructure. Finally, ATSC does not provide cancelling interference from transmitters not belonging to the DTS specific reference or training symbols. Cancellation is therefore difficult.

MBMS is tightly integrated into the WCDMA and LTE standards. With a firmware or software upgrade, User Equipment (UE) can gain MBMS capability, as it uses a common physical and MAC layer framework with the LTE unicast (i.e. mobile broadband) services. The technology entry barrier for supporting MBMS in the general LTE UE is therefore particularly low. LTE-MBMS can also be used in a downlink only fashion, which means that no return link is required from the broadcast receiver to the transmission infrastructure. MBMS can also be time-multiplexed with mobile broadband services, which can also be used to enable interactivity for the broadcast services or upcoming “Hybrid-Digital-TV” services [17].

We believe that LTE-MBMS is a suitable candidate for TV and audio broadcast distribution for the following reasons. We will show that dense deployments enable a better utilization of the frequency band that is allocated to TV. Deploying a dedicated dense broadcasting network is, however, not economically viable. Deployment of LTE networks for cellular mobile broadband communication in the market has already started and a strong buildout is expected. The presence of a substantial LTE infrastructure will obviate the need for investment in a dedicated infrastructure for exclusive TV broadcasting.

IV. SCENARIOS AND METHODOLOGY

A. Exemplary TV Broadcast Markets

We determine the amount of TV channels that are used for distributing TV programs in each of 4 exemplary markets.

- Raleigh-Durham (RDU), North Carolina,
- San Francisco bay area (SFBA), California,
- Lincoln-Kearney-Hastings (LIN), Nebraska, and
- Philadelphia (PHIL), Pennsylvania.

The characteristics of those markets are listed in TABLE I.

<table>
<thead>
<tr>
<th>Exemplary US TV markets</th>
<th>RDU</th>
<th>SFBA</th>
<th>LIN</th>
<th>PHIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population per km²</td>
<td>2,500</td>
<td>3,000-6600 (varies)</td>
<td>1,167</td>
<td>4,405</td>
</tr>
<tr>
<td># TV transmitter sites</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>total # TV channels</td>
<td>10</td>
<td>20</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>max # overlapping TV channels</td>
<td>9</td>
<td>20</td>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

The TV channel coverage contours are extracted from the FCC database [11]. By overlaying all contours we determine $N_{th}$ the maximum number of TV channels covering any point in the market. For the purposes of this paper, we assume that the typical offerings on a TV channel is 1 HDTV plus 1 SDTV. Bitrate efficiency gains of 30-50% have been reported. H.264 has been defined as one codec to be used with MBMS, however, for TV services targeting large screen additional H.264 profiles will have to be mandated for MBMS.

B. MBMS spectral efficiency simulation model

MBMS can be operated using QPSK, 16QAM or 64QAM, together with a fine granularity of turbo code rates. This allows optimal selection of the modulation and coding scheme (MCS) for the achievable SINR. We set the MCS so as to achieve 95% service availability considering uniformly distributed receiver locations, i.e. reception will fail with a 5% location probability. We do not consider atmospheric temporal variations of propagations as typically done in broadcasting propagation prediction (e.g. in [12]) because these variations are only significant over the very long propagation path relevant for networks with very low density, but not for cellular networks. The failure criterion is a block error rate (BLER) of $10^{-3}$. The failure behavior is very sharp, so that the result would not change significantly if a lower BLER was considered.

For the reference case we assume roof top reception at 10m height, with a Yagi antenna as defined in [13] with 10dBi gain according to [18]. The relative antenna gain is shown in Figure 1. We use this diagram for the horizontal pattern. For the
vertical dimension, which is of minor importance here we use omnidirectional gain. The antenna is pointed to the closest MBMS transmitter. In an alternative scenario we assume random pointing, modeling the case in which users do not change their roof-top antenna pointing when switching from the ATSC network to MBMS. We assume transmit and receive antennas to be co-polarized. In cellular networks 2 transmit antennas per cell which are cross-polarized to each other will increasingly be used in order to provide spatial multiplexing. With cross-polarized antennas available, the polarization plane can be adjusted as desired in order to match the receive antenna polarization plane, by adjusting the amplitudes of the co-phased signal fed into the transmit antennas. Circular polarization can also be achieved by using a phase offset of 90° between the signals. This has the advantage that both horizontally and vertically polarized receive antennas can be served with a polarization loss of at most 3dB.

We assume a receiver noise figure of 9dB. This also includes cable loss from the antenna to the receiver input.

Further simulations parameters are listed in TABLE II. Parameters not mentioned here are adopted from [14]. The modeled MBMS network consists of 19 transmitter sites, each equipped with 3 sectors. A single transmit antenna is used per sector. The simulation uses wrap-around technique to eliminate border effects for the simulation area.

The propagation model is also according to [14], except that the outdoor-to-indoor penetration loss is disregarded and 10dB lower pathloss is used to reflect the height difference between ground level and roof-top antennas.

MBMS can be configured with a core symbol duration of 66.7µs, guard interval of 16.7µs and subcarrier spacing of 15kHz or a core symbol duration of 133.3µs, guard interval of 33.3µs and subcarrier spacing of 7.5kHz. For fixed roof-top reception we assume the more appropriate long guard interval in our simulations.

We assume the receiver synchronizes to the first arriving signal. All signals arriving within the guard interval contribute to useful signal energy. We use 2 alternative models for inter-symbol-interference. The first one is a pessimistic model that all signals arriving after the guard interval contribute only to interference rather than any useful signal energy, even if a large part of the symbol interval falls within the receive window. The second model is according to [16] and it is more detailed in that it takes into account that also signals arriving after the guard interval to some extent contribute to useful signal energy. The signal contributes with a weight \( w_i \) to the useful signal \( C \) and with \( (1-w_i) \) to interference \( I \). The weight versus the signal reception delay is shown in Figure 2:

\[
\begin{align*}
    w_i &= \begin{cases} 
        0 & \text{if } t \leq \Delta - T_p \\
        \frac{(T_p + t)^2}{T_s} & \text{if } \Delta - T_p < t \leq 0 \\
        1 & \text{if } 0 \leq t \leq \Delta \\
        \frac{(T_p + \Delta - t)^2}{T_s} & \text{if } \Delta < t \leq T_p \\
        0 & \text{if } T_p < t 
    \end{cases}
\end{align*}
\]

and is defined as:

\[
    C = \sum_i w_i C_i \\
    I = \sum_i (1-w_i) C_i
\]

Where:

- \( C_i \) = the power contribution from the i-th signal at the receiver input
- \( C \) = the total power of the effective useful signal
- \( I \) = the total effective interfering power
- \( w_i \) = the weighting coefficient for the i-th component
- \( T_s \) = the useful symbol length
- \( \Delta \) = the guard interval length
- \( T \) = the signal arrival time
- \( T_p \) = the interval during which signals usefully contribute

The reason for the drop of the weight to zero at \( t = T_p \) is that the delay difference apart from the impact on ISI has also an impact on the coherence bandwidth. The LTE MBSFN reference signal pattern in time and frequency domain in case of the long guard interval provides one reference symbol on every 2nd sub-carrier (after time domain interpolation). Since

![Figure 1 Relative receive antenna gain for Band I, III, IV and V [13]](image)

![Figure 2 Signal weighting depending on delay [16]](image)
the subcarrier spacing is equal to the inverse of the OFDM symbol time $T_s$ (without guard interval), it follows that the channel estimation will deteriorate quickly for path delays larger than $T_s/2$. In contrast, for the simple ISI model the weight drops to zero already at $t_0 = \Delta = T_s/4$.

Our evaluation uses a propagation model according to [14], except that the outdoor-to-indoor penetration loss is disregarded and 10dB lower pathloss is used to reflect the height difference between ground level and roof-top antennas.

<table>
<thead>
<tr>
<th>parameter/model</th>
<th>value/description</th>
</tr>
</thead>
<tbody>
<tr>
<td>carrier frequency</td>
<td>600MHz</td>
</tr>
<tr>
<td>propagation model</td>
<td>3GPP Spatial Channel Model urban macro; 15° angular spread</td>
</tr>
<tr>
<td>transmit power</td>
<td>20W</td>
</tr>
<tr>
<td>sectors per site</td>
<td>3</td>
</tr>
<tr>
<td>BS antenna height</td>
<td>32m</td>
</tr>
<tr>
<td>modulation</td>
<td>4, 16 or 64 QAM</td>
</tr>
<tr>
<td>code rate granularity</td>
<td>0.01</td>
</tr>
<tr>
<td>target BLER</td>
<td>$1e^{-3}$</td>
</tr>
</tbody>
</table>

The LTE carrier bandwidth can be flexibly configured up to 20MHz. The MBMS spectral efficiency is independent of the considered bandwidth except for very low bandwidth of 5MHz and smaller. Therefore we show only values for 5MHz here.

V. RESULTS

A. Number of ATSC TV channels in use

We evaluate the number of TV channels that are in use in the USA for the four markets that have been described in section IV.A. The following Figure 4 to Figure 3 show the cumulatively available channels in those markets, derived from the coverage contours.

The largest number of simultaneously used channels is $N_{ch}=20$ and which can be found in the San Francisco Bay Area. With the assumed service rate of 13Mb/s per channel this results in a total service rate of 260Mb/s.
B. Required Spectrum for MBMS based TV broadcast

In order to determine the amount of spectrum required for TV broadcast transmission via MBMS, we first need to determine the spectral efficiency of MBMS which depends on the deployment parameters. We use the simulation model described in section IV.B, including ISI due to multiple transmitters. Figure 7 shows the MBMS spectral efficiency versus the inter-site-distance (ISD) for LTE subframes that are configured for MBMS. In these subframes we assume a configuration where no unicast control channels are present, such that all OFDM symbols can be used for MBMS transmission. The peak spectral efficiency of 3.1b/s/Hz is achieved for ISDs up to 2km. For the simple ISI model, the efficiency drops rapidly with increasing ISD. For the more realistic ISI model, however, a spectral efficiency of 3b/s/Hz can be maintained up to an ISD of 4km and the decay is less steep.

Figure 9 shows the SINR distribution over the receivers for the different ISD. For ISD=2km the 5%-SINR is well above the largest SINR value that can be exploited by 64QAM.

Comparing the SINR CDF with the SNR CDF in Figure 9 the reason for the decay is in fact the ISI of signals from remote transmitters, even for the detailed ISI model, and not the lack of sufficiently high receive signal power. With a guard interval of 33\(\mu\)s, a signal traveling 10km longer distance than the distance from the closest transmitter to the receiver do cause ISI. At an ISD of 3.5km such interference can arise from sites that are 3 tiers away from the receiver.

In the following we assume that an ISD of 2km is prevalent in the densely populated areas such as the San-Francisco Bay Area, where the number of available TV channels is also highest. In order to provide the total maximum service bitrate of 260Mb/s that we assume to be in use today by ATSC TV services, the total spectrum requirement for MBMS is:

\[
260\text{Mb/s} / 3.1\text{b/s/Hz} = 84\text{MHz}
\]  

(2)

It can be argued that the ISD can be higher in rural areas and consequently MBMS spectral efficiency will be lower according to Figure 7. However, we assume that the number of simultaneously available TV channels is also lower in these areas. Considering an ISD of 10km, which we assume is achieved even in rural areas, then the MBMS spectral efficiency is still 1b/s/Hz according to Figure 7 with a realistic ISI model. With 84MHz of spectrum this allows for 84Mb/s capacity. Based on 13Mb/s service rate per station this spectrum corresponds to the equivalent of 6.5 TV stations. This is more than twice of the maximum number of TV channels in use today in e.g. the Lincoln-Kearney-Hastings market.

We note that the more efficient spectrum usage of MBMS (84 MHz) compared to ATSC (300 MHz) can be assigned to two different effects. Currently, TV stations are not efficiently packed into the physical 6MHz channels. In our example of one HDTV and on SDTV station being transmitted via one ATSC channel, only 13 Mb/s are transmitted via a ATSC channel that is capable to transport up to 19.2 Mb/s. Consequently, 37% of the spectrum saving (i.e. 1-13Mb/s / 19.2Mb/s) is due to multiplexing TV programs, so that no unused capacity remains in the MBMS system. The remaining saving is due to the MBSFN transmission mode and short reuse distances against neighboring MBSFN areas. The spectral efficiency when neglecting the reuse distance is very similar between MBMS and ATSC, for which the efficiency can be calculated to 19.2Mb/s/6MHz=3.2b/s/Hz.

Additionally we show in Figure 10 and Figure 11 the spectral efficiency and SINR distribution for random pointing of the roof top antenna. Due to the MBMS single frequency network operation, the difference in distance between a receive antenna and the transmitters is often rather similar for the closest serving transmitters. As a result, the exact pointing direction of receive antennas is not important. Although Figure 11 shows a drop in SNR compared to the case of pointing to the closest BS, only minor degradation of the SINR and thereby the spectral efficiency can be seen for random antenna pointing. This means only a minority of users will have to re-point their antennas when they would want to “tune in” to MBMS. Mainly users at the border of an MBSFN area will be affected.
VI. TOTAL RADIATED POWER

Using a dense network for TV distribution instead of a sparse network raises the question of the impact on total power consumption. Considering only the total radiated power then network densification always allows a total power decrease as long as the constant term $\alpha$ and the exponent $\beta$ of a power-law propagation model (3) remain constant and the exponent is larger than that of free space propagation, i.e. larger than 2:

$$G = \alpha + \beta \log_{10}(d);$$

with $d$ being distance in meter and $G$ the pathgain in dB.

When comparing high tower networks with cellular low tower networks, however, $\alpha$ and to some extent also $\beta$ depend on the transmitter antenna height. We calculate the EIRP required by a single high transmitter to provide coverage in an area of a certain radius $r_{ATSC}$ considering the parameters of TABLE III. We use an ITU-R propagation model for TV broadcasting in which the antenna height above terrain is considered.

<table>
<thead>
<tr>
<th>TABLE III ASSUMPTIONS FOR EIRP COMPRISON</th>
</tr>
</thead>
<tbody>
<tr>
<td>parameter/model</td>
</tr>
<tr>
<td>carrier frequency</td>
</tr>
<tr>
<td>bandwidth</td>
</tr>
<tr>
<td>propagation model</td>
</tr>
<tr>
<td>SNR target</td>
</tr>
<tr>
<td>noise figure</td>
</tr>
<tr>
<td>receive antenn gain</td>
</tr>
<tr>
<td>shadowing margin</td>
</tr>
<tr>
<td>cellular ISD</td>
</tr>
<tr>
<td>high tower height</td>
</tr>
</tbody>
</table>

We also calculate the EIRP required by a cellular low tower transmitter with antenna height of 37.5m assuming some example ISDs for the cellular network. This EIRP per transmitter is then multiplied with the total number of transmitters required to cover the same area as the single high
tower transmitter. Figure 12 shows that a single high tower transmitter requires lower EIRP than a low tower network if the desired coverage radius is smaller than ~60km. The coverage radius we see in the FCC database for the considered ATSC tower height above average terrain of 500m are however, larger than this. Therefore, a net saving in total EIRP can be achieve with the dense lower tower network.

![Graph showing total EIRP of a single high tower transmitter and a network of low tower transmitters for the same total coverage radius](image)

In order to compare not only total EIRP but also power consumption, the power efficiency of transmitters needs to be taken into account. When using MBMS for TV distribution then only the power consumption required for generating and radiating the MBMS signal needs to be considered. Currently there is research ongoing on defining energy efficiency metrics and agreeing on models and parameters. However, to the best of our knowledge, these models so far consider only the total power consumption of a cellular base station and do not reveal the marginal consumptions of an extra carrier, not to mention considering the specific MBMS consumption. The power consumption for an MBMS carrier is in general lower than that of e.g. a LTE carrier used for mobile broadband, because an MBMS carrier does not use MIMO, does not require complex scheduling and does not implement an uplink.

An investigation considering network operation cost including high and low towers is presented in [20] where also a linear cost dependency on power per transmitter is considered. A power independent basic cost per low power transmitter is also taken into account; however, the cost relations are not completely revealed in the paper. We therefore refrain from comparing total power consumption or operation cost between high tower and low tower TV distribution networks at this point in time.

VII. CONCLUSION / DISCUSSION

We have investigated the spectrum requirements to provide roof-top reception, so far TV service using a cellular network deployment and the Multimedia Broadcast/Multicast Service (MBMS) of LTE. The spectral efficiency of MBMS for this application has been determined by simulations. From evaluating the FCC TV station database we determined the peak number of existing ATSC channels over 4 exemplary markets is 20 (San-Francisco Bay Area). Assuming 1 HDTV plus 1 SDTV program per channel we estimate a peak aggregate TV service rate of 260Mb/s is sufficient to provide today’s TV offering, which is based on MPEG2 video coding. Our study includes the gain from multiplexing programming from different sources.

![Graph showing total EIRP vs coverage radius for h=500m and h=37.5m](image)

Our simulations show that MBMS has a spectral efficiency of 3.1b/s/Hz up to a cellular inter-site-distance of 2km. With this, 85MHz of spectrum are sufficient to provide the desired aggregate service rate. Comparing this to the in total 300MHz used by TV services, the potential savings in spectrum are significant.

We find that the MBMS capacity for roof-top reception is not limited by transmit power for typical cellular transmitter densities, but rather by the self interference from signals arriving from transmitters with larger delay than the OFDM guard interval.

Due to the MBMS single frequency network operation, the exact pointing direction of receive antennas is not very important in most locations. This means only a minority of users will have to re-point their antennas when they would want to “tune in” to MBMS.

The cellular inter-site-distances we have considered are typically achieved by one cellular network alone. In principle it is possible that several cellular networks that are present in the same market provide MBMS services jointly, at least in geographical areas where cellular sites are sparsely deployed, in order to further enhance the service availability in these areas.

We note that spectrum requirements could be further reduced by replacing MPEG2 with H.264, for which bitrate efficiency gains of 30-50% have been reported. H.264 has been defined as one codec to be used with MBMS, however, for TV services targeting large screen additional H.264 profiles will have to be mandated for MBMS.
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ANNEX A: OVERVIEW OF MBMS ARCHITECTURE

The architecture for MBMS is depicted in Figure 13.

The architecture consists of the following entities:

- **BMSC (Broadcast/Multicast Service Center):**
  The BMSC serves as an entry point for content delivery services that use MBMS. Part of the functionality provided by the BMSC is comparable to that of an IP encapsulator in DVB-T/DVB-H services. However, due to the dynamic bearer management in MBMS, the BMSC functionality goes beyond that of an IP encapsulator. Towards the mobile core network it sets up and controls MBMS transport bearers and it can be used to schedule and deliver MBMS transmissions. The BMSC also provides service announcements to end-devices. These announcements contain all necessary information, such as multicast service identifier, IP multicast addresses, time of transmission, media descriptions, that a terminal needs in order to join an MBMS service. The BMSC can also be used to generate charging records for data transmitted from the content provider. It also manages the security functions.

- **MBMS gateway (GW):**
  The MBMS GW is an entity that is located between the content provider and the evolved transmitter stations (eNode B, or eNBs). The Control Plane (CP) of the MBMS GW is involved in the MBMS session start/setup. The user plane (UP) is responsible for delivering the user data over the IP multicast capable transport network to the eNBs and participates in the content synchronization for MBMS services using
MBSFN. The evolved MBMS gateway is part of the Evolved Packet Core (EPC).

- **MME (Mobility Management Entity):**
  In the context of MBMS, the MME is responsible for session control signaling.

- **MCE (Multicell/Multicast Coordination Entity):**
  The MCE is an entity responsible for coordinating the usage of MBSFN transmission in the LTE radio access network (RAN). This entity is part of the LTE RAN. The MCE is responsible for all the eNBs belonging to one MBSFN area.

- **eNB:**
  The eNB is the evolved transmitter station in LTE responsible for multiplexing, framing, channel coding, modulation and transmission.

The following logical interfaces are defined:

- **M1:**
  Is a logical interface between the MBMS GW and the eNBs. The transport on this interface will be based on IP multi-cast. The MBMS content is transported in a frame or tunnel protocol, in order to support content synchronization and other functionalities. IP multicast signalling is supported in the transport network layer in order to allow the eNBs to join an IP multicast group.

- **M2:**
  Is a logical control interface between the MCE and the eNBs. This interface is used to coordinate the setting up of an MBMS service in the eNBs for MBSFN operation. The signaling transport layer is based on IP.

- **M3:**
  Interface between MME and MCE. Supports MBMS Session Control Signaling, including the QoS attributes of each service (does not convey radio configuration data). The procedures comprise e.g. MBMS Session Start and Stop. SCTP is used as signaling transport i.e. point-to-point signaling is applied.

- **Sm:**
  The reference point for the control plane between MME and MBMS GW.

- **SGi-mb:**
  The reference point between the broadcast / multicast service center (BM-SC) and MBMS GW function for MBMS data delivery.

- **SGmb:**
  The reference point for the control plane between BM-SC and MBMS GW.