Power Efficient Resource Allocation Strategies for Layered Video Delivery Over eMBMS Networks

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***Abstract*—In this paper we propose couple power allocation strategies for layered video services delivery over evolved Multimedia Multicast/Broadcast Service (eMBMS) networks. The proposed allocations aim at reducing the power consumption of the eNodeB (eNB) and improving the user quality of experience characterizing the delivered eMBMS flows. We consider multiple challenging scenarios which differ by: (i) the number of eNBs transmitting the same service set, and (ii) how services are delivered. In particular, we consider scenarios where services can be delivered by resorting to the Random Network Coding principle or not. We compare the proposed resource allocation models to a strategy which equally shares the transmission power budget among layers of the delivered service. Analytical results show that the proposed resource allocation strategies are characterized by a transmission power which is on average 13% smaller than the considered alternative. In addition, the optimized resource allocation can deliver each layered video service over a geographical area which is up to 25% greater than that associated to the considered alternative.**

I. Introduction

Video traffic in mobile network is expected to grow of 60% per-year up to 2018 [1]. In addition, by 2018, the video content delivery will account for about half of the global mobile data traffic [2]. The exponential growth of multimedia applications is caused by the fact that multimedia-capable terminals (such as, smartphones, tablets, etc.) are even more diffused. 3GPP, starting from Release 6, defined an efficient and reliable solution to deliver, at the same time, multicast and broadcast services over a cellular network to User Equipments (UEs), namely the Multimedia Broadcast Multicast Service (MBMS) [3].

MBMS was defined for Universal Mobile Telecommunications Systems (UMTS) but, from 3GPP's Release 8, MBMS has been extended to the Long Term Evolution (LTE) standard. The updated version of the MBMS framework is called evolved MBMS (eMBMS) which specifies two transmission schemes: the Single Cell- (SC-) and Single Frequency Network-eMBMS (SFN-eMBMS). The first scheme provides that each eNodeB (eNB) delivers broadcast services independently from the others. On the other hand, the SFN-eMBMS mode is such that two or more eNBs are synchronised and deliver exactly the same MBMS data flow (i.e., eNBs delivers the same physical signals at the same time).

The current 3GGP's release (namely, Release 12) states that MBMS flows are delivered according to the Unacknowledged Mode provided by the Radio Link Control (namely, UM-RLC) level. Hence, multicast and broadcast services cannot benefit from any error control strategies such as Automatic Repeat-reQuest (ARQ) or Hybrid ARQ (HARQ) protocols. In addition, LTE standard does not specify the procedure that an UE (receiving eMBMS flows) has to follow to report the perceived communication quality level to the eNB. This means that UEs could not virtually transmit to the eNB any Channel Quality Information (CQI) feedbacks.

In order to improve the reliability of communications, Application Layer-Forward Error Correction (AL-FEC) codes have been proposed [4]. Usually, the AL-FEC coding is performed over Real-Time Transport Protocol (RTP) packets before they are mapped onto User Datagram Protocol (UDP) datagrams. Unfortunately, AL-FEC based strategies are characterized by large amount of redundancy (which impacts on the communication delay) between the application layer entities, compared to the short message transmission time required by multimedia applications.

Unlike AL-FEC strategies, Random Network Coding (RNC) schemes ([5], [6] and [7]) represent a valuable alternatives to the classical AL-FEC. In particular, authors in [6] propose an architectural design which integrate a RNC scheme directly into the Medium Access Control layer (namely, the MAC-RNC). Due to the fact that the MAC-RNC solution is characterised by a both reduced complexity and redundancy, we refer to that design whenever services are delivered according to the RNC principle.

It is worth noting that the Information and Communication Technology (ICT) area is responsible for 2-10% of the annual world-wide energy footprint [8]. Considering an LTE-based network, the eNB is the main element of energy consumption [9]. In addition, the multimedia content delivery in a multicast and broadcast mode is gaining momentum. To this end, this paper deals with minimization of the overall energy associated to the transmission of layered video services, according to the the eMBMS principle, over LTE-based networks. We proposed an Optimized Power Allocation (OPA) strategy for scalable video delivery, where each video service is encoded using the H.264 Scalable Video Coding (SVC). The H.264 SVC encoding process transform an high quality video stream into multiple video layers. In particular, the set of video layers consists of a base layer and several enhancement layers. The base layer allows UEs to achieve a very basic video quality level which can be improved by decoding one or more enhancement layers [10]. In the rest of the paper, we provide a resource allocation scheme that enable UEs, placed on a fraction of the cell-area, to recover a certain number of

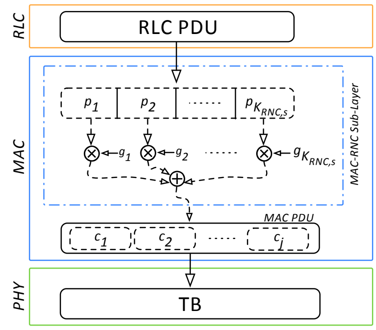

Fig. 1. LTE/LTE-A communication stack based on the MAC-RNC design.

video layers at a video quality level equal to (or more than) a threshold value. Moreover, to further improve communication reliability, we apply the MAC-RNC solution to the service delivery. We extend the OPA strategy to a RNC-based service delivery (namely, the OPA-RNC model) in order to optimize both the transmission power and the MAC-RNC transmission scheme. The results show that a UE can recover the basic layer while moves from a cell belonging to the SFN area to the next one.

The paper is organized in the following sections. Section II provides the background on MBMS services and an overview on power allocation strategies in LTE. Section III describes the system model and the H.264 SVC video delivery. In Section IV the proposed power allocation strategy is presented, firstly for video content delivery without using the RNC-MAC, then the same strategy is extended to the RNC-MAC case. Analytical results are presented in Section V. Finally, conclusions are given in Section VI.

II. Background

A. *eMBMS in LTE/LTE-A*

3GPP's Release 8 introduces two different eMBMS transmission modes: the Single-Cell (SC-eMBMS) and Single Frequency Network-eMBMS (SFN-eMBMS). The first one states that each eNB transmit the broadcast flow independently. In the SFN-eMBMS model, multiple eNBs are coordinated to cover an *MBMS area* (namely, a set of eNBs involved in the SFN-eMBMS delivery) with the same physical signals. Each UE treats the effects of the multi-cell transmission as well as multipath components of a single-cell transmission. The SFN-eMBMS mode leads to significant improvements in spectral efficiency compared to SC-eMBMS mode, particularly for the cell edge-users.

The challenge related to broadcast transmissions is represented by the choice of a Modulation and Coding Scheme (MCS) so that channel conditions experienced by UEs are taken into account. Even though UEs could report to the eNB the experienced propagation conditions, it is hard to tune MCSs in order to maximize (at the same time) the quality of experience of all the UEs. That issue is caused by the fact that the number of UEs could be high and they could experience quite different propagation conditions. Finally, that is more evident in a SFN-eMBMS service delivery where the number of UEs is greater than that in the SC-eMBMS case.

B. *Related Work*

In literature, several works address the problem of rate adaptation for multicast/broadcast systems. Among proposals two types of strategies can be identified: the fixed-rate and multi-rate transmission. In the case of the fixed-rate [11], one eNB transmits a service to all the UEs using a fixed MCS such that an hypothetical cell-edge user (namely, an UE placed on the cell-edge), even though there is no cell-edge user, receives the service with the desired quality level. That strategy guarantees a reliable service delivery but it is not inefficient from the point of the maximum achievable throughput and network capacity. The Least Channel Gain (LCG) [12] strategy provides that one eNB adaptively chooses the MCS according to the UE that actually is characterized by the worst propagation conditions. The main concern about the Fixed-Rate and LCG techniques is that the maximum transmission throughput is upper-bounded by those UEs experiencing the worst propagation conditions.

Multi-rate transmission schemes [13] deals with the heterogeneous propagation conditions of UEs by transmitting multiple data flows (characterized by different MCSs). In this way each UE recovers the delivered service at a certain quality which depends on the data flow that is successfully delivered. In this paper, we refer to a multi-rate transmission scheme where a broadcast flow is divided into several sub-flows, the Quality-of-Experience (QoE) of one UE depends on the number of sub-flows that can be recovered (i.e., the QoE increases if the number of recovered sub-flows rises). For these reasons, UEs experiencing the worst propagation conditions should be able to decode (at least) one sub-flow (namely, the one characterized by the smallest transmission rate).

For what concerns the power optimization and minimization strategies, it is worth to consider that green Information Technology is gaining momentum because of the climate change and the even more increasing demand for energy in 3G and 4G networks. Among the proposed solutions, it is worth to consider the proposal of Bousia *et al.* [9] for a dynamic network planning in which eNodeBs can be switched off if their traffic is offloaded to other cells. On the other hand, Luo *et al.* [14] propose to dynamically adapt the cell area (i.e., they propose to dynamically tune the transmission power) according to the user density. The aforementioned strategy assumes that both user positions and propagation conditions are known at the eNB side. In contrast, the power allocation strategy we propose does not require any feedback from UEs both in the case of SC-eMBMS and SFN-eMBMS delivery modes. In particular, we exploits the possibility to dynamically allocate the downlink transmission power in order to deliver an eMBMS service according to the multi-rate transmission principle. Finally, the proposed strategy provides a resource allocation such that UEs belonging to a certain fraction of the cell-area achieve (at least) a given QoE level.

III. System Model

The H.264 SVC standard [15] is one of the most popular video encoding solution. In particular, it aims at dividing the information flow in S different layers: one base layer (which can be independently decoded from other layers and represents

TABLE I
TB SIZE AND NUMBER OF CODED SYMBOLS PER RBP VS. CQI INDEX

i-th CQI Index	$t(MCS_i)$ bits per $N_{RBP} = 6$ RBPs	$f(MCS_i)$
1-3	No Transmission	No Transmission
4	384	2
5	576	3
6	768	4
7	960	5
8	1152	6
9	1536	8
10	1920	10
11	2304	12
12	2688	14
13	3072	16
14	3456	18
15	3840	20

a low-quality version of the delivered services) and $S-1$ enhancement layers (that can be combined to the basic layer to improve the overall video quality).

According to the LTE/LTE-A protocol stack [16], the IP packet stream representing the SVC video service is processed by the Packet Data Conversion Protocol (PDCP) and Radio Link Control (RLC) layers. In particular, the RLC layer produces a stream of RLC Protocol Data Units (PDUs) which are forwarded to the MAC layer. Each RLC PDU is segmented/concatenated into one or more MAC PDUs. Each MAC PDU is mapped on one Transport Block (TB). A TB consists of N_{RBP} Resource Block Pairs (RBPs), 1 RB is 12 OFDM subcarriers $\times 0.5$ ms, and one RBP (namely, a pair of RBs) is formed by 12 OFDM subcarriers and lasts one Transmission Time Interval (TTI), namely 1 ms. For the sake of the analysis, we assume that: (i) the RLC PDU size is equal to $L_{RLC} = 12000$ bits (i.e., the RLC PDU size is equal to a typical length of the IP packet payload[1]), and (ii) the value of N_{RBP} is set to 6 RBPs.

A. Directed H.264 SVC Video delivery

A SVC video stream consists of Group of Pictures (GoPs), which are a set of G contiguous video frames. Assuming that the video service imposes to deliver D frames per second, a GoP is transmitted every $T_{GoP} = \left\lfloor \frac{G}{TTI \cdot D} \right\rfloor$ TTIs. Finally, let R_s be the rate of the s-th SVC video layer, data related to the n-th layer of a GoP requires $K_{RLC,s} = \left\lceil \frac{G \cdot R_s}{D \cdot L_{RLC}} \right\rceil$ RLC PDUs to be delivered. In the rest of the paper, we define the s-th Service Zone (SZ) as the fraction of the cell area where (on average) all the UEs can recover the first s SVC video layers[2] (with a probability which is not smaller than a target value). Considering the s-th SVC video layer and assuming that TBs directed to SZ_s adopt the MCS associated to i-th CQI index (namely, MCS_i), one RLC PDU is mapped into $M(MCS_i) = \left\lceil \frac{L_{RLC}}{t(MCS_i)} \right\rceil$ MAC PDUs (i.e., TBs). Finally, values of the function $t(\cdot)$ are reported in Table I (which is based on Table I [6]).

Let us assume that TB reception errors are statistically independent events. Let Pe_s be the maximum TB Error Rate (TBLER) that characterizes the reception of an UE in SZ_s, the probability that U_s UEs (belonging to the s-th SZ) recover all the $K_{RLC,s}$ RLC PDUs of the s-th SVC video layer is:

$$\hat{B}_s(MCS_i) = Pe_s^{M(MCS_i)\, K_{RLC,s}\, U_s}. \tag{1}$$

Finally, UEs of SZ_s recover the first s SVC video layers with a probability which is equal to or greater than:

$$B_s(MCS_1, \ldots, MCS_s) = \prod_{j=1}^{s} \hat{B}_j(MCS_j). \tag{2}$$

B. RNC-based H.264 SVC Video delivery

The considered RNC principle [17] aims at delivery an information message composed by $p_1, \ldots, p_K$ information symbols. In this case, the transmitting node delivers to a set of UEs $c_1, \ldots, c_N$ coded symbols where $c_j = \sum_{j=1}^{K} g_j \cdot p_j$. It is straightforward to note that each coded symbol is a linear combination of the information ones where each coding coefficient g_j is randomly selected in the finite field F_q (of size q). As soon as one UE collects (at least) K linearly independent coded symbols, the information message can be recovered.

In this paper, we also consider the LTE-based system design proposed by Khirallah *et al.* [18] and sketched in Fig. 1. Hence, in this case we assume that the standard LTE MAC layer is modified in such a way that each RLC PDU is transmitted according to the RNC principle (namely, the MAC-RNC principle).

As for the s-th SVC layer of a GoP, it can be modelled as a stream of $K_{RNC,s} = \left\lceil \frac{G \cdot R_s}{D \cdot L_{RNC}} \right\rceil$ information symbols, each information symbol is L_{RNC} bytes long. In this paper, we assume that L_{RNC} is 4 bytes long. In this case, each TB (i.e., each MAC PDU), delivered by using the i-th MCS, can hold $C(MCS_i) = f(MCS_i) \cdot N_{RBP}$ coded symbols, where $f(MCS_i)$ expresses the number of coded symbols per RBP (see Table I). Finally, the probability that one UE of SZ_s recovers the s-th SVC video layer (i.e., the probability the one UE collects $K_{RNC,s}$ linearly independent coded symbols) after N_s TB transmissions can be expressed as [19], [20]:

$$P_{RNC,s}(MCS_i, N_s) = \sum_{t=\hat{N}_s}^{N_s} \binom{N_s}{t} Pe_s^{N_s - t} \left[1 - Pe_s\right]^t \cdot \cdot \prod_{j=0}^{K_s - 1} \left[1 - \frac{1}{q^{tC(MCS_i) - j}}\right]. \tag{3}$$

where $\hat{N}_s$ is the number of TB transmissions such that $\hat{N}_s \cdot N_{RBP} \cdot f(MCS_i) \geq K_s$.

The probability that U_s UEs recover the s-th SVC video layer of a GoP after N_s TB transmissions is:

$$\hat{B_n}(MCS_i, N_s) = \left[P_{RNC,s}(MCS_i, N_s)\right]^{U_s}. \tag{4}$$

Finally, all the UEs of SZ_s recover the first s SVC video layers with a probability which is at least equal to [20]:

$$B_{RNC,s}(N_1, \ldots, N_s, MCS_1, \ldots, MCS_s) = = \prod_{j=1}^{s} \hat{B}_j(MCS_j, N_j). \tag{5}$$

[1]For the sake of simplicity both the impact of the IP packet and RLC PDU headers is not considered.

[2]This means that the SZ receives the basic SVC video layer and the first $s-1$ enhancement ones.

TABLE II
SYSTEM PARAMETERS CONSIDERED

Parameter	Value
Antenna Gains	See Table A.2.1.1.2-2 [23]
Shadowing	10 dB (See Table A.2.1.1.5-2 [23])
Penetration Loss	20 dB (See Table A.2.1.1.5-2 [23])
Path-Loss	Path-loss Line Of Sight (LOS) case $PL_{LOS}(d) = 103.4 + 24.2\log_{10}(d)$
	Path-loss Non LOS (NLOS) case $PL_{NLOS}(d) = 131.1 + 42.8\log_{10}(d)$
	Probability of LOS reception $P_{LOS}(d) = \exp(-(d-0.01)/0.2)$ (See Table A.2.1.1.5-2 [23])
Noise Power	-168
Carrier Frequency	2GHz
System Bandwidth	20 MHz
Max Tx. Power	80 W (49 dBm) (see Table A.2.1.1-2 [23]

IV. POWER ALLOCATION FOR SC- AND SFN-EMBMS SYSTEMS

This section deals with the OPA and OPA-RNC allocation strategies. Due to the fact that LTE/LTE-A standard states that one eNB can dynamically adapt the transmission power on a TTI base [21], [22], we aim at defining a green power allocation model. In particular, we propose an allocation model such that: (i) the overall transmission power (at the eNB side) is minimized, and (ii) UEs belonging to SZ_s can recover the first s SVC video layers with a certain probability.

Let us consider a network scenario composed by B contiguous eNBs organized in two concentric rings. It is worth defining the average Signal-to-Interference plus Noise Ratio (SINR) associated to an UE placed at a distance d from a reference eNB (namely, b_i) in an SC-eMBMS data delivery scenario, which can be defined as follows:

$$\mathit{SINR}(d) = \sum_{t=1}^{B} p_t\, h_t(d). \tag{6}$$

where p_t is the power associated to one TB transmitted by the t-th eNB. In addition the term $h_t(d)$ can be defined as [6]:

$$h_t(d) = G_{eNB} + G_{UE} - N - Sh - PL(d) - \delta_t\, I_t(d). \tag{7}$$

where the terms G_{eNB} and G_{UE} are the antenna gains of the eNB and UE, respectively. The noise power (at the UE side) is N, while Sh is the shadowing loss. The path-loss function $PL(d)$ can be expressed as follows (see Table II):

$$\begin{aligned} PL(d) = P_{LOS}(d) \cdot PL_{LOS}(d) + \\ +\Big(1 - P_{LOS}(d)\Big) \cdot PL_{NLOS}(d). \end{aligned} \tag{8}$$

The function $I_t(d)$ represents the Inter-Cell Interference (ICI) power generated by the interfering eNBs. Of course, in an SC-eMBMS scenario, there are $B-1$ eNBs which interfere with the UE reception (namely, all the eNBs interfere with the UE reception except for b_i). To this end, the term δ can be defined as:

$$\delta_t = \begin{cases} 0, & \text{if } t = b_i \\ 1, & \text{otherwise.} \end{cases} \tag{9}$$

Considering a SFN-eMBMS data delivery over a SFN composed by $\hat{B}$ contiguous cells. The SINR value characterizing the reception of an UE (belonging to the SFN) can be expressed as reported in (6). Unlike the SC-eMBMS scenario, there are $B - \hat{B}$ eNBs which interfere with the UE reception. Hence, the term δ_t has to be redefined as follows:

$$\delta_t = \begin{cases} 0, & \text{if } t\text{-th eNB belongs to the SFN} \\ 1, & \text{otherwise.} \end{cases} \tag{10}$$

Let us consider an SVC video delivery which do not rely on RNC (see Section III-A). Considering the s-th SVC video layer, if it is delivered with a transmission power P_s (i.e., if each TB delivery data of the s-th layer of a GoP is transmitted with a power P_s) and the s-th MCS then an UE (placed a distance d from the transmitting eNB) receive the SVC layer at a data rate which, from Eq. (1):

$$r_s(P_s, \mathit{MCS}_s, d) = \hat{r}_s\, \hat{B}_s(\mathit{MCS}_s). \tag{11}$$

where $\hat{r}_s$ is the bitrate of the s-th SVC layer. Of course both P_s and d impact on the SINR associated to the considered UE. Hence, for different values of P_s and d, Pe_s (and hence, $\hat{B}(\mathit{MCS}_s)$) may change. Finally, the OPA model can be defined as follows:

$$\text{(OPA)} \qquad \min_{\substack{P_1,\dots,P_S \\ \mathit{MCS}_1,\dots,\mathit{MCS}_S \\ d_1,\dots,d_S}} \sum_{s=1}^{S} P_s \tag{12}$$

subject to

$$r_s(P_s, \mathit{MCS}_s, d_s) \geq \hat{r}_s, \qquad s \in \{1,\dots,S\} \tag{13}$$

$$d_s \geq \hat{d}_s, \qquad s \in \{1,\dots,S\} \tag{14}$$

$$Pe_s \leq \hat{P}e, \qquad s \in \{1,\dots,S\}. \tag{15}$$

The constraint (13) ensures that each SVC layer is received in SZ_s of radius d_s. In the rest of this section we approximate each SZ as a circular area. Constraints (14) and (15) impose that the SZ radius is equal to or greater than a certain value $\hat{d}_s$, and that the TBLER associated to an UE of SZ_s (and place at a distance d_s from the eNB) has to be not greater than $\hat{P}e = 0.1$.

Let us consider a RNC-based service delivery (see Section III-B). From Eq. (4), Eq. (11) can be restated as follows:

$$r_s(P_s, \mathit{MCS}_s, d, N_s) = \hat{r}_s\, \hat{B}_s(\mathit{MCS}_s, N_s). \tag{16}$$

From (16), the OPA-RNC model can be extended as follows:

$$\text{(OPA-RNC)} \qquad \min_{\substack{P_1,\dots,P_S \\ \mathit{MCS}_1,\dots,\mathit{MCS}_S \\ d_1,\dots,d_S,N_1,\dots,N_S}} \sum_{s=1}^{S} P_s \tag{17}$$

subject to

$$r_s(P_s, \mathit{MCS}_s, d_s, N_s) \geq \hat{r}_s, \qquad s \in \{1,\dots,S\} \tag{18}$$

$$N_s \leq T_{GoP}, \qquad s \in \{1,\dots,S\} \tag{19}$$

$$d_s \geq \hat{d}_s, \qquad s \in \{1,\dots,S\} \tag{20}$$

$$Pe_s \leq \hat{P}e, \qquad s \in \{1,\dots,S\}. \tag{21}$$

Unlike OPA model, the OPA-RNC also aims at optimizing the number of TB transmissions characterizing each video layer. To this end, constraint (19) states that the number of TB transmissions of each layer has to be not greater than the GoP duration (expressed in terms of number of TTIs).

TABLE III
H.264 SVC VIDEO STREAMS

Video stream A [25]		Video stream B	
Rate [kbps]	**PSNR [dB]**	**Rate [kbps]**	**PSNR [dB]**
160.0	29.45	117.1	29.94
300.0	32.30	402.5	34.78
560.0	34.52	1506.3	40.73
1150.0	38.41	-	-

Of course the overall transmission power per TTI cannot exceed the maximum power budget $\hat{P}$. To this end, a solution to the problems OPA and OPA-RNC is considered valid only if the following relation holds:

$$\sum_{s=1}^{S} P_s \leq \hat{P}. \quad (22)$$

Both versions of the proposed allocation strategy are suitable for SC- and SFN-eMBMS data delivery. In addition, from the service provider point of view, each problem has to be solved just before beginning the video service delivery. Finally, in this paper, both OPA and OPA-RNC have been solved by resorting to genetic strategies [24].

V. NUMERICAL RESULTS

This section deals with the performance evaluation and comparison of the OPA and OPA-RNC models with an Uniform Power Allocation (UPA) model that: (i) do not rely on the RNC principle, and (ii) equally splits the power budget among all the delivered SVC video layers. Finally, the UPA strategy does not have any cell coverage constraints.

We simulated an urban (3GPP case 1 [23]) scenario composed by $B = 19$ macro-cells eNBs deployment (characterized by system parameters reported in Table II), where the inter-site distance is 500 m. Both TBLER and SINR values experienced by UEs have been simulated by resorting to the simulation model proposed in [18]. Finally, in the case of RNC communications, we considered a finite field of size $q = 2^8$.

We consider an SC-eMBMS service delivery where, one eNB delivers one video service at time. In the SFN-eMBMS case, we consider an SFN area composed of 4 adjacent cells. We evaluate the performance of the proposed allocation strategy by using two different H.264 video streams (see Table III). We impose that each SVC layer has to be successfully received (at least) over a certain fraction of the cell-area. In particular, the basic layer and three enhancement layers of video A have to be successfully received over the 90%, 60%, 50% and 30% of the cell-area, respectively. Finally, for what concerns the video stream B, the basic layer and the remaining two enhancement ones have to cover (at least) the 90%, 60% and 30% of the cell-area, respectively.

The system performance is investigated in terms of overall transmission power, maximum achievable datarate ($\tilde{R}$) and maximum achievable PSNR ($\tilde{P}$) defined as:

$$\tilde{R} = \begin{cases} \max\{\tilde{r}_s \, B_s(MCS_1, \ldots, MCS_S)\}, & \text{Non RNC Case.} \\ \max\{\tilde{r}_s \, B_s(N_1, \ldots, N_s, MCS_1, \ldots, MCS_S)\}, & \text{RNC Case.} \end{cases} \quad (23)$$

$$\tilde{P} = \begin{cases} \max\{\tilde{p}_s \, B_s(MCS_1, \ldots, MCS_S)\}, & \text{Non RNC Case.} \\ \max\{\tilde{p}_s \, B_s(N_1, \ldots, N_s, MCS_1, \ldots, MCS_S)\}, & \text{RNC Case.} \end{cases} \quad (24)$$

where $\tilde{r}_s$ and $\tilde{p}_s$ are the bitrate and PSNR that we get by combining the first s SVC layers.

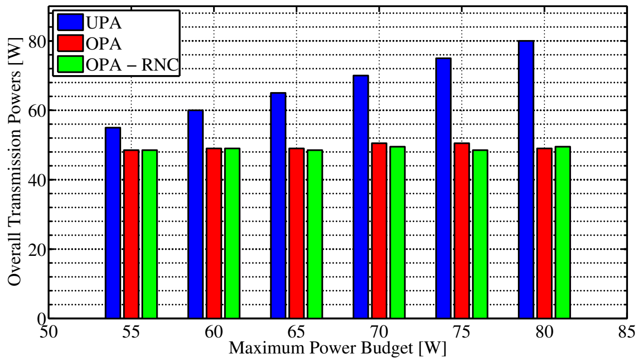

Fig. 2. Overall transmission power vs. total power budget.

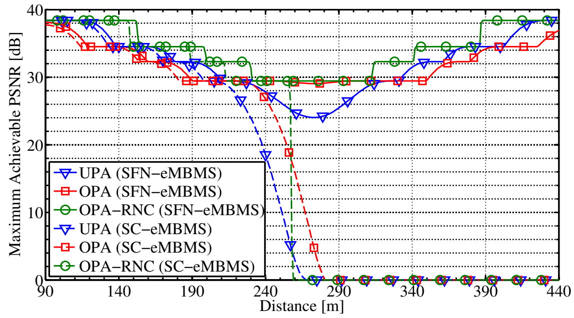

Fig. 3. Maximum achievable PSNR vs. distance from the eNB for video stream A.

Considering an SFN-eMBMS data delivery. Fig. 2 compares the overall transmission power that is actually consumed by the eNB as a function of $\hat{P}$. In particular, the figure shows that both the OPA and OPA-RNC based allocation models significantly outperform the UPA strategy. Of course, the performance gain increases as the maximum power budget rises.

Figs. 3 and 4 compare the performance of all the considered allocation models for video streaming A in both SC-eMBMS and SFN-eMBMS delivery case. In particular, figures show $\tilde{P}$ and $\tilde{R}$, respectively and as a function of the distance from the eNB. It is worth noting that, in an SC-eMBMS delivery scenario, the UPA strategy successfully delivers the service up to a distance of 205 m which is smaller than that we have with the OPA and OPA-RNC strategy (221 m and 258 m, respectively). Let us compare both OPA and OPA-RNC solutions, the second allocation model can deliver the same QoE level over SZ which are wider than those associated to the OPA model. That is caused by the RNC-based service delivery.

Let us consider again Figs. 3 and 4. In the SFN-eMBMS case, it is worth noting that both the OPA and OPA-RNC allocation strategies provide an allocation such that (at least) the basic layer is successfully received while UE moves from a cell to the next one. On the other hand, in the UPA case the delivered service may be not successfully recovered by cell-edge UEs.

Figs. 5 and 6 show maximum achievable data rate and PSNR, respectively for the video service B. Also in this case we note that both the OPA and OPA-RNC outperform the UPA strategy in terms of service coverage area. Once again, the OPA-RNC strategy is characterized by SZs which are greater

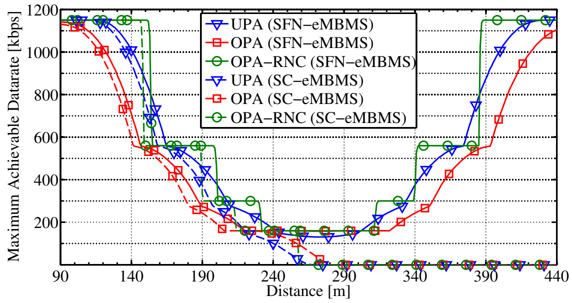

Fig. 4. Maximum achievable datarate vs. distance from the eNB for video stream A.

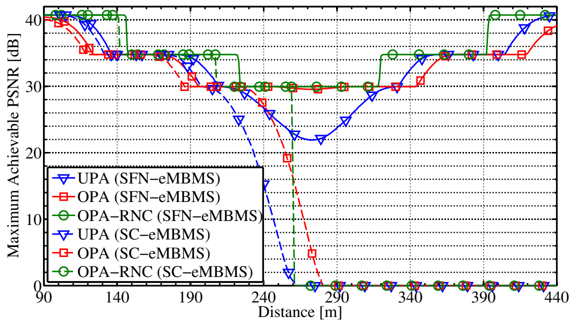

Fig. 5. Maximum achievable PSNR vs. distance from the eNB for video stream B.

than those defined by the OPA model.

VI. Conclusions

In this paper, we propose a couple of resource allocation strategies (OPA and OPA-RNC) aiming at minimizing the transmission power consumption of eNBs delivery eMBMS broadcast layered video services. Initially, we propose an allocation model which directly addresses the transmission power reduction issue. Afterwards, this model is been extended to enable a RNC-based service delivery. The performances of the proposed approaches have been investigated by comparing them with a widely used uniform power allocation strategy (UPA). The analytical results show that for different maximum power budget both the proposed strategies are characterized by a transmission power reduction which is up to 40% smaller than that of the UPA strategy. In the case of SC-eMBMS, both the OPA and OPA-RNC can deliver video contents over SZs which are respectively 12% and 25% wider than those associated to the UPA model. Finally, in the case of SFN-eMBMS, both the proposed allocation models provide a resource allocation such that (at least) the basic SVC video layer can be recovered by UEs passing from one cell to another one belonging to the same SFN.

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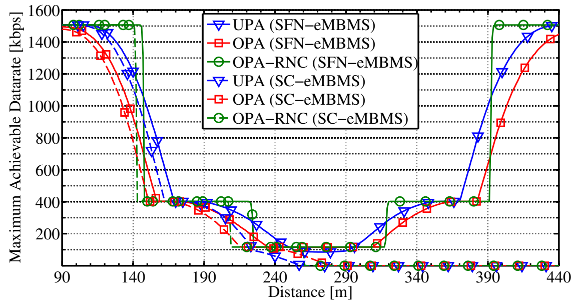

Fig. 6. Maximum achievable datarate vs. distance from the eNB for video stream B

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