



# An Adaptive Power Control Scheme for Multicast Service in Green Cellular Railway Communication Network

Jiying Huang<sup>1</sup> · Zhangdui Zhong<sup>2</sup> · Jianwen Ding<sup>1</sup>

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**Abstract** Along with emerging increasing multimedia service need from the big amount of users in the train, wireless cellular railway network has big energy saving potential with its own specific characteristics, which is widely deployed over the world. Enhanced Multimedia Broadcast Multicast Service (E-MBMS) is a prevalent solution for high speed data handling. In this paper, to achieve an energy efficient solution for wireless cellular railway network, we proposed an optimal power control solution to adjust eNodeB's transmission power adaptively based on actual Signal to Interference plus Noise Ratio (SINR) for Multimedia Broadcast multicast service Single Frequency Network (MBSFN) at User Equipment (UE) side when provide E-MBMS. We established the system model and proposed the optimization algorithms to calculate the E-MBMS transmit power. We also designed the geometry group scheme to significantly reduce the calculation effort. And proposed the Mobility offset parameter to cope with high speed mobility of the train and variation of signal level. Finally, Simulation results showed that this solution can be a good way for high network energy efficiency and can

dynamically adjust the output power for the multicast service in the wireless cellular railway communication network.

**Keywords** Downlink power control · MBSFN · Multicast service · Green cellular railway network

## 1 Introduction

Wireless cellular communication network are currently experiencing surging traffic load and energy consumptions. According to the Green radio report [1], users and network devices in mobile and wireless networks consume 57 % of the energy of the information and communication technology (ICT) industry, and the scale of which is still growing exponentially [2]. So it is crucial to have energy efficient solution for wireless cellular network. Network equipment vendors, Mobile Operators and Academic researchers already started lots of cooperation activities to develop new technologies for energy efficiency improvement in cellular network. Such as the GreenTouch consortium [3], the COST action IC1004 [4], and funded projects like EARTH [5], C2POWER [6], TREND [7], and Mobile VCE [8]. Besides, standardization bodies like IEEE, ITU, and ETSI also work on energy efficiency activities for cellular network.

Along with sharply increase of smartphones, tablets and laptops, multimedia services becomes a very prevalent solution for the high speed data need. Based on this situation, beyond MBMS (Multimedia Broadcast Multicast Service) in E-UTRAN (Evolved Universal Terrestrial Radio Access Networks), E-MBMS (Enhanced Multimedia Broadcast Multicast Service) was introduced in the Release 8 of 3GPP standard. E-MBMS can be provided with single frequency network mode of operation, called Multimedia Broadcast Single Frequency Network (MBSFN). In that case the

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✉ Jiying Huang  
[ejying@126.com](mailto:ejying@126.com)

Zhangdui Zhong  
[zhdzhong@bjtu.edu.cn](mailto:zhdzhong@bjtu.edu.cn)

Jianwen Ding  
[jwding@bjtu.edu.cn](mailto:jwding@bjtu.edu.cn)

<sup>1</sup> School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing, China

<sup>2</sup> State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China

multicast transmission technique is realized by the transmission of identical waveforms at the same time from multiple cells. That is using the same RBs among different cells to provide synchronous transmission for E-MBMS service. A MBSFN Transmission from multiple cells within the MBSFN Area is seen as a single transmission by a UE. At the same time, it is still possible that a cell within a MBSFN Area which does not contribute to the MBSFN Transmission (Fig. 1).

The current cellular railway network e.g. GSM-R is designed to be the control base that administers the operation of the trains and organizes the transportation between the trains. Over the world, there are thirty-eight countries selected the cellular network for railways, like China, Germany, Italy, etc. [9]. For a single 4/4/4 configuration, a Base Station (BS) consumes 26,000 kWh per year [10]. Taking a 240 km railway line as example, it will consume 2,080,000 kWh per year with 3 km coverage per one BS, which is a huge cost and the large CO<sub>2</sub> emission. Besides, today's people are used to have multimedia service at anytime and anywhere, unfortunately the current cellular railway network can't meet emerging huge multimedia traffic generated by smartphone revolution. Since E-MBMS standards allow multicasting, i.e., transmitting data over a radio channel to multiple users simultaneously, and it can be accomplished by using existing cellular networks with minor modifications, thus allowing for multicast services can be delivered economically and energy efficiently. However, compared with a public mobile cellular network, a wireless communication network deployed for railway can be characterized by specific chain structure, high speed mobility, high security requirement, frequent and continuous handover, predictable traffic aligned with train schedule and the big group of users concentrated in the train. All these specifics not only stand for opportunity for more efficient E-MBMS design in cellular railway network, but also the big challenges that how to achieve this target within existing E-MBMS design framework.

Downlink Power control is a good approach for high network energy efficiency, which is widely used in the cellular network to help operators reduce overall Operating Expense (OPEX). Energy cost is a significant part of an operator's OPEX. Downlink power control is the way to balance traffic load, coverage and energy efficiency to achieve the integrated best performance at system level. According to latest 3GPP standard (TS 36.300) [11], there is no information about how to decide downlink power control for multi-cell transmission mode. The default power setting is not optimal for multi-cell transmission mode in E-MBMS, since in the most situations UE will receive much stronger signal power level than that for the robust coding scheme.

In this paper, we try to address the energy efficiency issue based on the multi-cast service in cellular railway network. There are three major challenges in this study. The first one

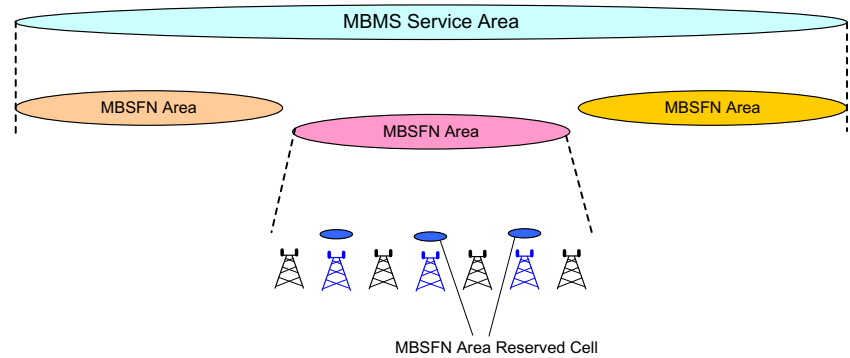
is how to make sure the transmit power for the whole railway cellular network is the lowest. To cope with this challenge, a new power control algorithm based on the actual SINR was proposed to achieve the best network energy efficiency of the whole network. The second one is how to automatically adjust transmit power of eNodeB without complex calculation. In this paper, a "Geometry group" scheme was designed to heavily reduce the calculation effort. The third one is how to avoid the ping-pang-adjustment of the eNodeB transmit power caused by high speed mobility of the train. In order to solve the third challenge, a parameter "mobility offset" was presented in the algorithm to manage the high speed movement. At last, we adopted the real railway scenario and deployment data for the simulation, and get significant energy savings effect. Compared with studies in the literature related to green cellular communication techniques, our contribution covers many aspects:

- To the best of our knowledge, this is the first paper to propose an energy efficient solution for EMBMS service in a green cellular railway network;
- We propose an optimal power control algorithm to adjust transmission power adaptively based on actual SINR for MBSFN;
- We design the detail "Geometry group" approach in our study, and MCE can easily calculate the transmit power for each eNodeB without complicated computation;
- We propose the "Mobility offset" parameters to cope with high speed movement of the train and variation of signal level;
- We evaluate our method using the data from scenarios of railway networks, to identify the effect of energy saving along with different factors. Compared with the scheme without power control strategy, our solution has efficient power saving without impact of receive signal strength level variations and train speeds.

The remainder of this paper is organized as follows. In section 2, we briefly review the related work in this area, and in Section 3, the system model and the proposed algorithm are introduced. In Section 4, the simulation result is presented, followed by concluding remarks in Section 5.

## 2 Related work

There are many studies on energy efficiency in green wireless cellular network. We can categorize them into 3 major aspects: The first one is bringing energy efficient architecture change in Base station, like minimizing energy consumption of Base Station by improvements in HW component [12], designing power saving protocols [13], implementing cooperative Base Station power management [14, 15], and so on. The second

**Fig. 1** E-MBMS area definition

one is energy efficient network planning, different types of network deployments based on smaller cells can be used to increase the energy efficiency of a cellular network [16, 17]. The third one is making efficient wireless system design, eg: Using modern communication technologies such as cognitive radio and cooperative relays to enable green communication in cellular systems [18, 19].

Base station HW component improvements such as using more energy-efficient power amplifiers [20], using natural resources for cooling are the common approaches. Ericsson  $\Psi$  (Psi) [21] and Flexenclosure E-site solutions [22] are examples of such efforts. However, these approaches are not sufficient to handle the energy waste in a railway cellular network. In railways, the cellular network keeps running, even no trains in their area, which results in much energy waste by BSs. Dynamic energy-efficient base station operation has recently received significant attentions [23, 24], corresponding traffic load are transferred to neighboring cells during periods of low utilization. The concept of self-organizing networks [25] has been applied by operators to achieve energy optimization. However, many of these works are only focused on ideal networks such as hexagonal model network, and they introduced that the energy consumption could be saved by dynamic base station switching algorithms. As conventional macro-cellular network deployments are less efficient in high data rate, heterogeneous network deployment is a promising solution for dense traffic area. Femtocell deployment could have a 7:1 operational energy advantage ratio over the expansion of the macro cell network to provide approximately similar coverage [26]. However in railway scenario, the traffic load is not the bottleneck and normally much less than public network. Heterogeneous network solution cannot solve the fundamental energy waste in railway cellular network.

In [27], an efficient Handover schemes and algorithm in high-speed mobile railway environments are proposed to reduce handover times and secure handover performance, meanwhile with less handover energy and resources. The solution has good energy saving effect in handover procedure, but which is a quite small proportion of entire railway cellular network, cannot solve the energy waste problem primarily. Literature [28] proposed an energy saving solution in railway

cellular network. Based on the train schedule information from the railway control system, railway cellular network can startup or shutdown the radio modules in Base Station and save the energy for whole network. This method can make good contribution on energy saving in railway cellular network. However, it highly relies on the input from the railway control system, which is not always available in railway cellular network.

A power allocation algorithm for multicasting by using multi-BS systems is considered in [29]. The algorithm was designed to operate the power allocation for each Base Station in turn iteratively until the power allocations for all BSs become stable. But this solution requires very long convergence period and sensitive for UE mobility. Furthermore many proposals have studied the possibility with uplink feedback channel for E-MBMS. In this way, HARQ and AMC could be used in MBSFN transmission to improve radio resource efficiency [30, 31]. However, with this solution, all UEs need keep reporting CQI and ACK/NACK to eNodeB all the time. As E-MBMS users increase, the cost of uplink reports also increases consequentially, which goes against large scale deployment of E-MBMS. On the other hand, these kinds of solutions are not compatible with existing 3GPP standard at UE side, which also brings extra cost for commercial deployment. In [32], a two-phase algorithm that allocates power, frequency, and time resources to maximize sum of given utilities in delivering MBMSs over an MBSFN have been proposed, where the utility function can be defined according to the system objectives. But the algorithm complexity is considered too high to meet high mobility scenario. Furthermore, all the work mentioned above miss the content that discuss if their algorithm also applicable for cellular railway network and what adaption should be made for best use the property in cellular railway network.

In summary, there is no direct related work to design efficient E-MBMS transmission solution by jointed consideration of special challenges and opportunities (specific chain structure network deployment, high speed

mobility, frequent handover, predicable traffic aligned with train schedule and the big group of users concentrated in the train) from railway scenario for green communication in cellular railway network.

### 3 Styling system model and the proposed solution

#### 3.1 System model

We consider a wireless cellular railway network which contains a set of  $N$  cells, covering railway tracks as shown in Fig. 2. Multi-cell/multicast Coordination Entity (MCE) is responsible for the allocation of time and frequency resources for multi-cell MBMS transmission. The eNodeBs in these cells can provide MBSFN for multicast service, and each eNodeB  $i$  can adjust its transmit power  $P_{T_i}^{mbsfn} \in [0, P_{T_i}^{max}]$  for each physical resource block (PRB), which are allocated by multi-cell transmission mode in E-MBMS service.

In order to provide better network service, the scheduled trains have been equipped with  $L$  relays. These relays can receive messages from eNodeBs, and then transfer to UEs within its coverage. Besides, these relays are also in charge of Channel Quality Indicator (CQI) measurement, and periodically send measurement reports to eNodeBs. To simplify our system model, we don't consider Doppler frequency shift issue which may bring some incorrect signal measurements for high speed train. There are many research and technologies [33] can help with Doppler frequency shift estimation and pre-compensation.

In E-MBMS service, there are multi-paths between relay and eNodeBs, each relay  $i$  detect and measure the transmitted power  $P_{R_i}$  at time  $t$ , which can be defined as formula (1).

$$P_{R_i}(t) = \sum_{k=1}^N P_{R_{ki}}(t) \tag{1}$$

$P_{R_{ki}}(t)$  is the received power, hereby after known as relay  $i$  from a eNodeB  $k$ . And it is obviously that  $P_{R_i}(t)$  is the sum of received power from a series of eNodeB at time  $t$ . It is easy to get a threshold  $R_i$  to establish a constraint for  $P_{R_i}(t)$  to ensure that it can get the benefits from the E-MBMS service. Then we have,

$$P_{R_i}(t) = \sum_{k=1}^N P_{R_{ki}}(t) \geq R_i, i \in [1, L] \tag{2}$$

$N$  is the total number cells as mentioned above, along with the railway track.

According to the definition of cell specific reference (CSR) signal, we define eNodeB  $k$  transmit power as  $P_{T_k}^{CRS}(t)$  at time  $t$ , and the receiving signal of relay  $i$  from eNodeB  $k$  as  $P_{R_{ki}}^{CRS}(t)$ .

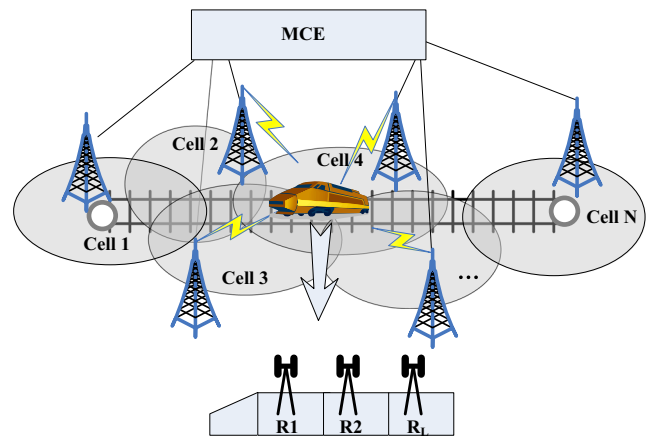


Fig. 2 System model

We get the long-term path-loss channel attenuation  $\gamma_{ik}(t)$  between the relay  $i$  and eNodeB  $k$  as

$$\gamma_{ik}(t) = \frac{P_{R_{ki}}^{CRS}(t)}{P_{T_k}^{CRS}(t)} \tag{3}$$

And we can calculate  $P_{R_{ki}}(t)$  as following.

$$P_{R_{ki}}(t) = \gamma_{ik}(t) \times P_{T_k}^{mbsfn}(t) = \frac{P_{R_{ki}}^{CRS}(t)}{P_{T_k}^{CRS}(t)} \times P_{T_k}^{mbsfn}(t) \tag{4}$$

From green communication perspective, our energy saving objective is to minimize the total transmit power  $P_{T_k}^{mbsfn}(t)$  of all eNodeBs that providing E-MBMS service and serving all passengers on the train in the railway network. Meanwhile, all those eNodeBs also need to transmit enough power to maintain the service in the cells of the relays under eNodeBs' coverage. So, the objective can be expressed as formula (5):

$$\begin{aligned} \min \mathcal{E} &= \min \sum_{k=1}^N \sum_{\Delta t} P_{T_k}^{mbsfn}(t) \times \Delta t \\ \text{s.t. } \sum_{k=1}^N P_{R_{ki}}(t) &= \sum_{k=1}^N \gamma_{ik}(t) \times P_{T_k}^{mbsfn}(t) \geq R_i \\ P_{T_k}^{mbsfn}(t) &\in [0, P_{T_k}^{Max}] \\ &i = 1, \dots, L \end{aligned} \tag{5}$$

However, above formula will bring the big computation-complexity effort for MCE (Multi-cell/multicast Coordination Entity) who is responsible for the time and frequency resources allocation. Besides, there is another serious issue when relays are moving forward along the railway track with in E-MBMS service, the procedure of recalculating  $P_{T_k}^{mbsfn}(t) \in [0, P_{T_k}^{Max}]$  will keep all the whole time to dynamically adjust transmit power to meet communication requirement, which may bring the huge uplink traffic. Therefore, in this paper, we provide a geometry group method to improve computation

efficiency and modify the measurement report policy to decrease uplink traffic.

### 3.2 Geometry group based power control solution

In the system model, relays can measure the cell specific reference (CSR) signal in its served cell and neighbor cells, then generate the measurement reports and send them to eNodeBs periodically or on demand according to configuration policies. In this paper, we invoke a scheme that relays can ignore those neighbor cells in which Reference Signal Receiving Quality (RSRQ) levels are lower than a specific threshold  $\Gamma$  to decrease the computation complexity and reduce the uplink data amount. The specific threshold  $\Gamma$  is a preset value by eNodeBs, can be sent to these relays with other cell parameters during the initial and negotiation phase between eNodeBs and relays. Although these neighbor cells can also make contribution to provide E-MBMS

service, considering as the extra signal gain, the absence of these signal will not impact the quality of E-MBMS service.

In this case, assume that a relay  $k$  can receive CSR signal with a certain received power from eNodeB  $i$  when the received power  $P_{R_{ki}}^{CRS}(t) \geq \Gamma$ . And set the constraint of eNodeB quantity as  $M$ , which is just sufficient to meet specific area's service need. Then the communication area of these cells can be divided into  $\varphi$  geometric sub-regions. Where,

$$\varphi = \sum_{j=0}^{M-1} C_{M-1}^j \quad (6)$$

In order to decrease the constraints in the above system model, we provide Algorithm 1 to form geometry group and select useful constraints in each geometry group. "Geometry" is only the expression of concept, and no geographical position and communication range of eNodeBs are required.

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#### Algorithm 1 The outline of the proposed method

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1: Input: the number of relay  $L$ , each relay measures RSRQ level by CSR signal from served
   cell and neighbor cells which the received power  $P_{R_{ki}}^{CRS}(t) \geq \Gamma$ . We name geometry
   group set as  $\Theta = \{G_0, \dots, G_{M-1}\} = \{g_1 = \emptyset, \dots, g_\varphi = \emptyset\}$  for each eNodeB. Each
   geometry group  $g_v$  has factor table  $T_v = \{t_{1v}, \dots, t_{Nv}\} = ones(1, N)$ 
2: WHILE(TRUE)
3:   FOR  $t = t_0$  to  $t_0 + \Delta t$  DO
4:     IF eNodeB receives measurement report THEN
5:       eNodeB checks the number of neighbor eNodeBs  $u$  in the measurement report,
       and adds RSRQ level information into  $G_u$  for the group  $g_w$  with the same neighbor
       eNodeBs combination;
6:     END IF
7:   END FOR
8:   FOR  $j = 1, \dots, \varphi$  DO
9:     eNodeB selects the minimum RSRQ level by CSR signal from each  $g_w^* \in$ 
      $\{g_1, \dots, g_\varphi\}$ , and then removes others RSRQ level information
10:  END FOR
11: eNodeB sorts RSRQ level for group  $\{g_{(1)}^*, \dots, g_{(\varphi)}^*\}$  in the ascending order
12: FOR  $j = 1, \dots, \varphi$  DO
13:   eNodeB sets  $T_v = zeros(1, N)$  for group  $g_v^* \in \{g_{j+1}^*, \dots, g_{(\varphi)}^*\}$  with the same
   neighbor eNodeBs combination as  $g_j^*$ 
14: END FOR
15: eNodeB sends  $\{g_{(1)}^*, \dots, g_{(\varphi)}^*\}$  information and  $\{T_1, \dots, T_\varphi\}$  to MCE for transmitted
   power calculation
16:  $t = t_0 + \Delta t$ 
17: END WHILE

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Geometry group based power control solution can greatly decrease the constraints in formula (5) of system

model, and also bring less computation complexity to solve the optimization problem by many LP algorithms.



As shown in formula (5), there are always  $L$  inequality constraints for each computation cycle. In cellular railway network, the number of relays in the trains  $L$  is much larger than the number of eNodeBs  $N$ . We select  $\varphi$  geometric sub-regions by small value  $M$ , and it is reasonable especially in linear deployment of cellular railway network. In the worst case, each etric sub-region has one inequality constraint and we totally have  $\varphi \ll L$  constraints to solve the optimization problem.

Taken example in this case as  $M=3$ . Figure 3 is a common wireless coverage style in the cellular railway system. In the area of eNodeB Q, according to the Algorithm 1, four sub-regions Q(1), Q(2), Q(3) and Q(4) with different constraints are marked, where relays can receive the minimum CSR signal strength in each of the four sub-regions. We also define 4 relays, relay<sub>1</sub>, relay<sub>2</sub>, relay<sub>3</sub> and relay<sub>4</sub> accordingly. Thus, we can decrease the computation complexity by ignoring many inequalities via execute the following process:

- If  $P_{R_{k1}}^{CRS}(t) = \min \{P_{R_{k1}}^{CRS}(t), \dots, P_{R_{k4}}^{CRS}(t)\}$ , where  $k=1..3$ , that is relay<sub>1</sub> is the one with minimum CSR signal strength of 4 relays, only  $P_{R_{k1}}^{CRS}(t)$  needs to satisfy the constraint in section 3.1. Therefore, we can set other factor table  $T_2, T_3, T_4$  with zeros which means to discard these constraints. Therefore there is only one inequality constraint for our algorithm.
- If  $P_{R_{k2}}^{CRS}(t) \vee P_{R_{k3}}^{CRS}(t) = \min \{P_{R_{k1}}^{CRS}(t), \dots, P_{R_{k4}}^{CRS}(t)\}$ , where  $k=1..3$ ,  $P_{R_{k1}}^{CRS}(t)$ ,  $P_{R_{k2}}^{CRS}(t)$ , and  $P_{R_{k3}}^{CRS}(t)$  need to satisfy their constraints. The constraint for  $P_{R_{k4}}^{CRS}(t)$  can be ignored by  $T_4 = \text{zeros}(1, N)$ . In this case, the constraints decrease the one with all 4 relays.
- If  $P_{R_{k4}}^{CRS}(t) = \min \{P_{R_{k1}}^{CRS}(t), \dots, P_{R_{k4}}^{CRS}(t)\}$ , where  $k=1..3$ , there are all four constraints required.

### 3.3 Mobility offset

As relays will move together with the trains along the track by a high speed, the receive power  $P_{R_{ki}}^{CRS}(t)$  for relay  $i$  will also change during the E-MBMS service process because of the jitter or variation of signal level. In order to decrease the uplink communication and transmitter power recalculation effort caused by the mobility of train, we defined a mobility offset  $\delta_k$ , where,

$$\delta_k = \frac{\Delta P_T^{CRS}}{P_{T_k}^{CRS}(t)} \tag{7}$$

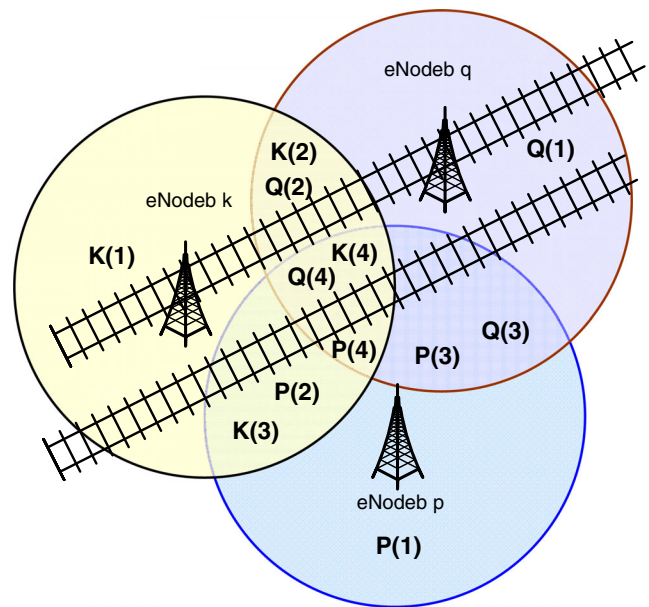


Fig. 3 A method of geometric sub-regions

And it is easy to define a new threshold  $\Delta P_T^{CRS}$  when the variation of received power  $P_{R_{ki}}^{CRS}(t)$  is within  $\delta_k \times P_{T_k}^{CRS}(t)$  at time  $t$ , then we get:

$$\sum_{k=1}^N (\gamma_{ik} - \delta_k) \times P_{T_k}^{mbsfn}(t) \geq R_i \tag{8}$$

This equals to the below the equation

$$\sum_{k=1}^N \gamma_{ik} \times P_{T_k}^{mbsfn}(t) \geq \sum_{k=1}^N \delta_k \times P_{T_k}^{mbsfn}(t) + R_i \tag{9}$$

Based on the assumption in Section 3.2, relay  $i$  can obtain and send CSR signal measurement report from eNodeB  $k$  when the receive power  $P_{R_{ki}}^{CRS}(t)$  is higher than  $\Gamma$ . We set a group  $\Lambda_k$  for a eNodeB  $k$  of relay  $i$ , in which for any relay  $i$  and  $k \in \Lambda_i$ , it can make sure that  $P_{R_{ki}}^{CRS}(t) \geq \Gamma$ .

Then we have,

$$\sum_{k=1}^N \delta_k \times P_{T_k}^{mbsfn}(t) + R_i = \sum_{k=1, k \in \Lambda_i}^N \delta_k \times P_{T_k}^{mbsfn}(t) + R_i \leq \sum_{k=1, k \in \Lambda_i}^N \delta_k \times P_{T_k}^{Max} + R_i \tag{10}$$

Now we get the new dynamic service threshold  $\sum_{k=1, k \in \Lambda_i}^N \delta_k \times P_{T_k}^{Max} + R_i$ , which is only decided by set  $\Lambda_i$  for each relay  $i$ . And the set  $\Lambda_i$  can easily obtained by each eNodeB and sent to MCE.

Therefore, if the variation of  $P_{R_{ki}}^{CRS}(t)$  is less than  $\Delta P_T^{CRS}$ , the relay  $i$  will not send measurement report to eNodeB. And we can get  $\Delta t$  in Algorithm 1 by:

$$\Delta t = \min_i \arg \max_{\Delta t} \left\{ |P_{T_k}^{CRS}(t + \Delta t) - P_{T_k}^{CRS}(t)| < \delta_k \times P_{T_k}^{CRS}(t) \right\} \quad (11)$$

### 3.4 Calculation of the E-MBMS transmit power

After MCE receives the measurement information  $\langle \gamma_{ik}(t), \sum_{k=1, k \in \Lambda_i}^N \delta_k \times P_{T_k}^{Max} + R_i, T_v \rangle$  from specific geometry group  $v$  of eNodeB  $k$ , the system model in section 3.1 will update to solve the below constraints at time  $t$ :

$$\begin{aligned} & \min \sum_{k=1}^N P_{T_k}^{mbsfn}(t) \\ s.t. & \sum_{k=1}^N \gamma_{ik}(t) \times t_v \times P_{T_k}^{mbsfn}(t) \geq \sum_{k=1, k \in \Lambda_i}^N \delta_k \times P_{T_k}^{Max} + R_i \quad (12) \\ & P_{T_k}^{mbsfn}(t) \in [0, P_{T_k}^{Max}] \\ & i \in \Theta \end{aligned}$$

The target is converted to an optimization problem. Many LP algorithms can be employed to get optimized transmit powers. In geometric terms, the feasible region of optimization problem is a bounded convex polytope from the constraint condition. And a minimum point of the objective function is the extreme points or vertices of this polytope. As mentioned above, since there are a finite number of extreme points, this problem can be solved using linear programming such as simplex algorithm or Lagrange function with finite computation.

## 4 Simulation result

In this section, we simulate the power saving effect for our proposed power control strategy in multicast service of cellular railway communication network. We adopted the real railway deployment scenario and data as simulation input. In the Fig. 4, we set the railway tracks between A and B as 10 km, and the cells between A and B have good coverage for MBSFN service. The different trains can run on the bi-directional railway track with two different directions. In order to handle our simulation, we select Hata model [34] in urban area to simulate the received power  $P_{R_{ki}}^{CRS}(t)$  for each UE  $i$  in the cell  $i$  at time  $t$ . Hata model is the most widely used radio frequency propagation model for predicting cellular transmissions in wireless communication area. The path loss  $L$  can be expressed in the equation bellow, we select frequency  $f = 2000$  MHz,  $H_b$  and  $H_m$  are the heights of base stations and relays antenna in the train.

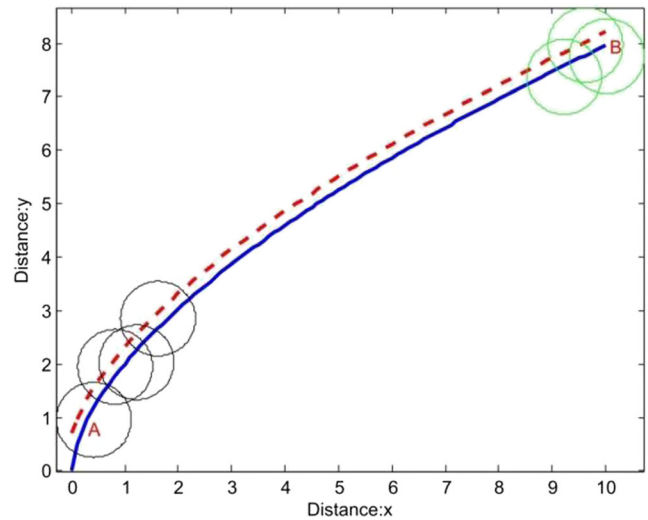


Fig. 4 Simulation scenario

$$\begin{aligned} L(dB) = & 69.55 + 26.16 \log f - 13.82 \log(H_b) \\ & + [44.9 - 6.55 \log(H_b)] \log(d) - a(H_m) \quad (13) \end{aligned}$$

The part  $a(H_m)$  is the correction factor:

$$a(H_m) = 3.2 * (\log 11.75 H_m)^2 - 4.97 \quad (14)$$

More parameters can be found in Table 1. Firstly, we set up our simulation scenario that two trains are scheduled bi-directionally from two sites, and each BS will collect the measurement reports from the relays in the trains. If the receive power  $P_{R_{ki}}^{CRS}(t)$  varies more than  $\delta_k \times P_{T_k}^{CRS}(t)$ , the BS will collect relay’s measurement information and send to MCE which can carry out power control solution. In MCE, simplex algorithm is selected to calculate the transmitted power  $P_{T_k}^{mbsfn}(t)$  of each eNodeB at time  $t$ . In the next subsections we will evaluate the power control efforts for two specific marginal cells and central cell, and then show the power consumptions with different receive power signal level variations. In the following, we will investigate the power control times and power consumption with different train speeds.

### 4.1 Power control effect for specific cells

The two trains are scheduled bi-directionally from two sites, and their relays will send the measurement report of cell reference signal if they can receive it in the cellular range. Firstly we select  $\delta_k = 1/15$ , and if eNodeB detects the CRS variant ratio more than  $\delta_k$ , the MCE will calculate the transmit power of EMBMS by the above algorithm. In Fig. 5, the specific marginal cell receives the E-MBMS transmit power at the beginning and at the end because one train is scheduled from A site to B Site and the other train is from B site to A site. The central cell can have more continuous time interval for

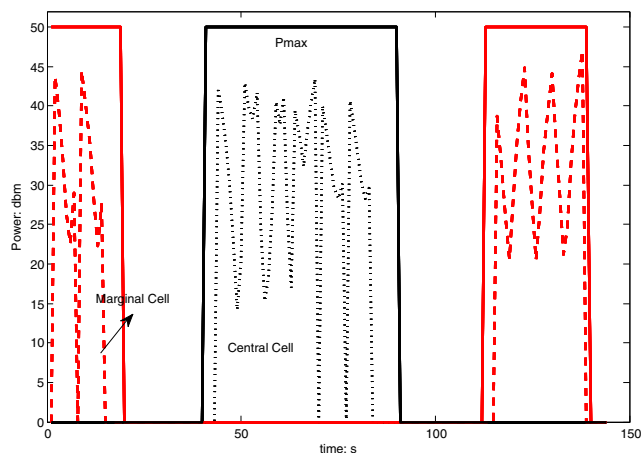
**Table 1** Scenario parameters

| Parameter                     | Value                      |
|-------------------------------|----------------------------|
| Number of BSs                 | 28                         |
| BS MBFSN max power            | 100w (50dbm)               |
| BS CSR transmit power         | 100w (50dbm)               |
| Cell radius avg.              | 0.7 km                     |
| Transmit frequency            | 2000 MHz                   |
| Height of BS antenna $H_b$    | 45 m                       |
| Height of Relay antenna $H_m$ | 2.5 m                      |
| Relay number in train         | 3                          |
| Train Speed                   | 160, 180,200, 220,240 km/h |
| signal threshold of E-MBMS    | -75dbm                     |

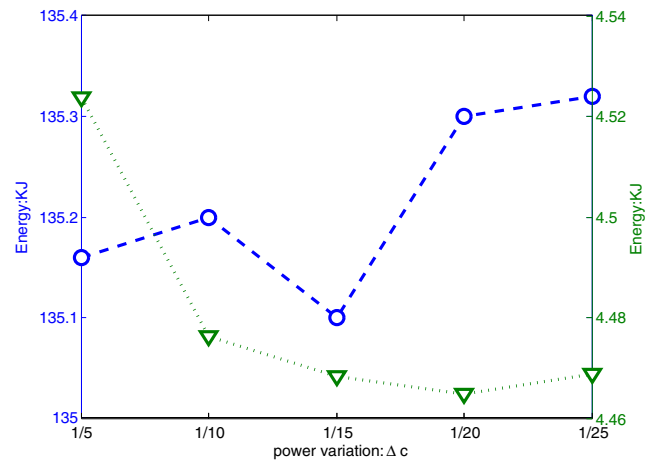
E-MBMS transmission during two trains’ overlap period. In traditional way, for both marginal cell and central cell, eNodeB will always keep its maximum transmit power once it can provide E-MBMS service for trains. From the simulation result, we can see our power control solution can decrease the transmit power, even to zero during some time interval when other neighbor cells’ transmission can cooperatively cover the service. It means our method can be a good way for high network energy efficiency and able to dynamically adjust the output power for the multicast service.

**4.2 Impact of receive power signal strength level variations**

Because the trains move along the railway track, the measurement report will be varied in the different locations. It is impossible to calculate the transmit power all over the time because of the high computation consumption and uplink transmission cost. In this section, we select several typical signal strength level variations to adjust the threshold in our simulation, and calculate the whole power consumptions of all eNodeBs with formula  $\sum_{k=1}^N \sum_{\Delta t} P_{T_k}^{mbsfn}(t) \times \Delta t$  for each signal strength level variation. In the Fig. 6, blue curve is the



**Fig. 5** Power control effect for two specific marginal cell and central cell



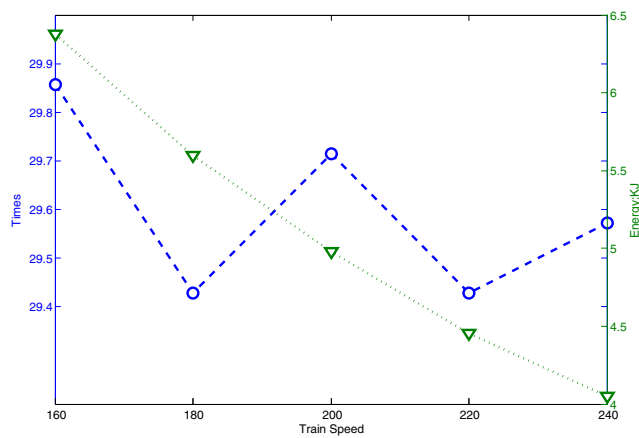
**Fig. 6** The impact of receive power signal level variation

power consumption statistics for all eNodeBs without downlink power control during two trains’ running. It is relative flat due to maximum transmit power provided for E-MBMS service. After the railway cellular network applied our downlink power control solution, the power consumption statistics for all eNodeBs is the green curve in the Fig. 6. It shows total power consumptions for all eNodeBs are much less than the consumptions without power control strategy. Through the Fig. 6, we can also see with higher receive power signal level variation, the transmitted power in the constraint needs more margins to satisfy E-MBMS requirement, and the smaller variation requires more frequently carry out power control solution.

**4.3 Impact of train speeds for power control strategy**

We also evaluate the energy saving impact of train speeds on our power control solution. Speed parameters can be found in Table 1. Firstly we still select  $\delta_k = 1/15$  as the same in section 4.1, and if eNodeB detects the CRS variant ratio more than  $\delta_k$ , the power control strategy will be carried out according to our algorithm. In our simulation model, the noise fraction is omitted in Hata model, and the measurement report can give accurate received power indications. Therefore CRS variant ratio will not be impacted by train speed. We also calculate the whole power consumptions of all eNodeBs with formula  $\sum_{k=1}^N \sum_{\Delta t} P_{T_k}^{mbsfn}(t) \times \Delta t$  in each scenario with different train speed. As shown in left curve (blue one) of Fig. 7, the average time of power control in total eNodeBs is almost the same between low speed 160 km/h and high speed 240 km/h. The small difference shown in figure may be caused by different train speeds when the train enter or leave the serving cells during the measurement report period. Besides, the high train speed can have shorter E-MBMS serving time of eNodeBs, and when no trains pass through the serving cell, E-MBMS transmit power will be zero. We can see the lower power consumptions





**Fig. 7** The impact of train speeds

for high speed 240 km/h in the right curve (green one) of Fig. 7.

## 5 Conclusions

Wireless cellular communication network are currently experiencing surging traffic load and energy consumptions, energy efficiency are getting extremely high attention from academy researchers, vendors, and operators. With increasing multimedia service need from the big amount of users in the train, wireless cellular railway network has big energy saving potential with its own specific characteristics. They are chain structure network deployment, high speed mobility requirement, frequent and continuous handover, predicable traffic aligned with train schedule and the big group of users concentrated in the train. These entire specific bring both opportunities and challenges for energy efficiency of E-MBMS in wireless cellular railway network. We proposed a new power control algorithm based on the actual SINR in E-MBMS to automatically adjust transmit power of each eNodeB and eventually achieve the lowest transmit power for the whole network; we designed a “Geometry group” scheme to do easy calculation; and we also proposed a parameter “mobility offset” in the algorithm to manage the high speed movement to avoid the ping-pang adjustment. Finally, we built our simulating environment based on a real cellular railway network, and the numerical results showed the power control effect for specific cells in E-MBMS is quite good, and also showed that energy saving can be achieved with different receive power strength levels and different train speeds. Considering Doppler frequency shift effect can bring incorrect signal measurement for relays in high speed train, future study will provide additional model to handle the issue and also apply for heterogeneous network energy saving, which cover both railway and the habitants along the railway tracks.

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