Communication Cost Analysis of MBSFN in LTE

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Abstract— **Long Term Evolution (LTE) is the latest step towards the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile communications. To support Multimedia Broadcast/Multicast Services (MBMS), LTE offers the possibility to transmit Multimedia Broadcast multicast service over a Single Frequency Network (MBSFN), where a time-synchronized common waveform is transmitted from multiple cells for a given duration. In this paper we analytically present the MBSFN delivery method and evaluate its performance. The critical parameters of primary interest for the evaluation of the scheme are the packet delivery cost and its scalability. To this direction, a telecommunication cost analysis of the MBMS service is presented based on the transmission cost over the air interface, as well as the costs of all interfaces and nodes of the MBSFN architecture. Since the performance of the MBSFN scheme mainly depends on the configuration of the LTE network that is under investigation, we consider different network topologies, MBSFN deployments and user distributions.**

Keywords- LTE, MBSFN, cost analysis, e-MBMS

I. INTRODUCTION

The Long Term Evolution (LTE) project is focused on enhancing the Universal Terrestrial Radio Access (UTRA) and optimizing 3GPP's (3rd Generation Partnership Project) radio access architecture. LTE supports scalable carrier bandwidths, from 20 MHz down to 1.4 MHz and provides downlink peak rates of at least 100 Mbps, an uplink of at least 50Mbps and round-trip times of less than 10 ms. Orthogonal Frequency Division Multiplexing (OFDM) has been selected for the downlink and Single Carrier-Frequency Division Multiple Access (SC-FDMA) for the uplink.

The 3GPP has introduced the Multimedia Broadcast/Multicast Service (MBMS) as a mean to broadcast and multicast information to 3G and 4G users. MBMS is an efficient method of delivering multimedia content to multiple destinations, by allowing resources to be shared in an economical way [1], [2].

In the context of the "Long Term Evolution" of 3G systems the MBMS will evolve into the e-MBMS [3] ("e-" stands for evolved). The LTE e-MBMS aims at providing broadcast and multicast services combining flexibility and high efficiency in the spectrum occupancy. This will be achieved through increased performance of the air interface that will include a new transmission scheme called Multimedia Broadcast multicast service over a Single Frequency Network (MBSFN).

In MBSFN operation, MBMS data is transmitted simultaneously over the air from multiple tightly time-synchronized cells. A group of those cells which are targeted to receive the broadcast MBSFN data constitute a so called MBSFN area. All cells within an MBSFN area contribute to the MBSFN transmission and advertise its availability. A User Equipment (UE) receiver will therefore observe multiple versions of the signal with different delays due to the multicell transmission. In effect, this makes the MBSFN transmission, as seen by the UE, a transmission to a single large cell, and the UE receiver may treat the multicell transmissions in the same way as multipath components of a single-cell transmission without incurring any additional complexity. The UE does not even need to know how many cells are transmitting the signal.

The MBSFN transmission mode leads to significant improvements in spectral efficiency compared to Universal Mobile Telecommunications System (UMTS) MBMS, as the MBSFN transmission greatly enhances the Signal to Interference Noise Ratio (SINR). This is extremely beneficial at the cell edge, where transmissions (which in UMTS are considered as inter-cell interference) are translated into useful signal energy and hence the received signal strength is increased while, at the same time the interference power is largely reduced [4]. In general MBSFN offers better performance compared to classic single cell point-to-point (PTP) or point-to-multipoint (PTM) transmissions [5]. Moreover, the performance of the MBSFN transmission depends on the number of cells transmitting the MBSFN service. Specifically, it has been proven that the MBSFN performance in the air interface increases drastically when apart from the cells that contain users, neighboring cells assist in the MBSFN transmission as well [6].

In this paper we evaluate the MBSFN delivery scheme in terms of packet delivery cost, cost for control procedures (synchronization, polling) and scalability of the scheme. Furthermore, since the performance of this scheme depends mainly on the configuration of the LTE network that is under investigation, we consider different network topologies, MBSFN deployments and user distributions. Based on these telecommunication cost parameters, we calculate the total telecommunication cost required for the transmission of the MBSFN data to mobile users of a given MBSFN service. To our knowledge an end to end cost based evaluation approach of MBSFN has not yet been studied and it is our belief that this approach could conclude to more sophisticated results than focusing only on the spectral efficiency in the air interface.

Finally, we estimate how many neighboring cell rings should be included in the same MBSFN area and thus transmitting in the same frequency with the cells that actually contain users, in order to achieve high SFN gains with the lowest possible cost with respect to users' distribution in the topology.

The paper is structured as follows: in Section II, an overview of MBSFN architecture is presented. The telecommunication cost analysis of the MBSFN delivery scheme is described in Section III. In Section IV we present the evaluation results and in Section V, the conclusions and planned next steps are briefly described.

II. Overview of E-MBMS LTE Architecture

The e-MBMS architecture is illustrated in Figure 1. Within e-UTRAN (evolved UTRA Network), the e-NBs (evolved Node B or base station) are the collectors of the information that has to be transmitted to users over the air-interface. The MCE (Multi-cell/multicast Coordination Entity) is coordinating the transmission of synchronized signals from different cells (e-NBs). MCE is responsible for the allocation of the same radio resources, used by all e-NBs in the MBSFN area for multi-cell MBMS transmissions. Besides allocation of the time/ frequency radio resources, MCE is also responsible for the radio configuration e.g. selection of modulation and coding scheme. The e-MBMS GW (e-MBMS Gateway) is physically located between the e-BM-SC and e-NBs and its principal functionality is to forward the MBMS packets to each e-NB transmitting the service. Furthermore, e-MBMS GW performs MBMS Session Control Signaling (Session start/stop) towards the e-UTRAN via MME (Mobility Management Entity). The e-MBMS GW is logically split into two domains. The first one is related to control plane, while the other one is related to user plane. Likewise, two distinct interfaces have been defined between e-MBMS GW and e-UTRAN namely M1 for user plane and M3 for control plane. M1 interface makes use of IP multicast protocol for the delivery of packets to e-NBs. M3 interface supports the MBMS session control signaling, e.g. for session initiation and termination [3], [4].

The e-BM-SC (evolved Broadcast Multicast Service Center) is the entity in charge of introducing multimedia content into the 4G network. For that purpose, the e-BM-SC serves as an entry point for content providers or any other broadcast/multicast source which is external to the network.

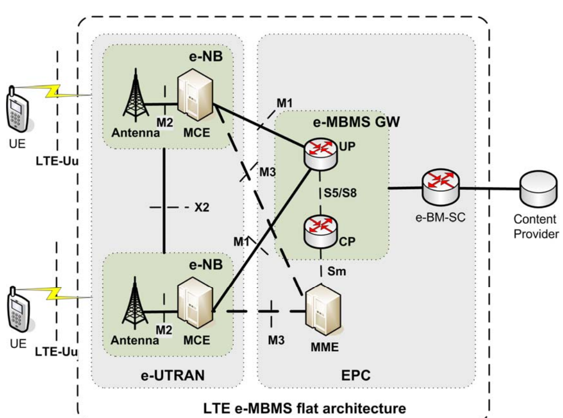

Figure 1. e-MBMS flat architecture.

Regarding the air (or LTE-Uu) interface, MBSFN uses two logical channels in downlink, namely Multicast Traffic Channel (MTCH) and Multicast Control Channel (MCCH). MTCH is a PTM channel for transmitting data traffic to the UEs residing to the service area. On the other hand, MCCH is a PTM downlink channel used for transmitting MBMS control information from the network to UEs and is associated to one or several MTCHs. MCCH and MTCH are only used by UEs that receive MBMS traffic. Both MCCH and MTCH are mapped on the Multicast Channel (MCH), a transport channel at the Medium Access Control (MAC) layer. MCH is mapped on the Physical Multicast Channel of the physical layer [3], [7].

III. Cost Analysis of MBSFN

In this section, we present a performance evaluation of MBSFN delivery scheme. As the performance metric for the evaluation, we consider the total telecommunication cost for both packet deliveries and control signals transmissions [8]. In our analysis, the cost for MBSFN polling is differentiated from the cost for packet deliveries. Furthermore, we make a further distinction between the processing costs at nodes and the transmission costs on links in accordance with [8]. For the analysis, we apply the notations presented in Table I:

TABLE I. Notations

Abbreviation	Explanation
D_{Uu}	Transmission cost of single packet over Uu interface
C_{Uu}	Total transmission cost over Uu (air) interface
D_{M1}	Transmission cost of single packet over M1 interface
C_{M1}	Total transmission cost over M1 interface
$C_{polling}$	Total transmission cost for polling
C_{SYNC}	Total processing cost for synchronization at e-BM-SC
D_{p_eNB}	Cost of polling procedure at each e-NB
D_{M2}	Transmission cost of single packet over M2 interface
N_p	Total number of packets of the MBSFN session
N_{eNB}	Number of e-NBs that participate in MBSFN
N_{cell}	Total number of e-NBs in the topology
N_{p_burst}	Mean number of packets in each packet burst
C_{MBSFN}	Total telecommunication cost of the MBSFN delivery

Before presenting in detail the above parameters, some general assumptions of our analysis and the topology under examination are presented.

A. General Assumptions and Topology

We assume that the topology is scalable and has the possibility to consist of an infinite number of cells according to Figure 2. Moreover, in order to calculate the total cost, we assume that the users can be located in a constantly increasing area of cells in the topology, called "UE drop location cells". Therefore, in the case when UE drop location cells is equal to 1, all users are located in the center cell (see Figure 2). The six cells around the center cell constitute the inner 1 ring. Likewise, the inner 2 ring consists of the 12 cells around the first ring. Following this reasoning we can define the "inner 3 ring", the "inner 4 ring" etc. In this paper the following user distributions are examined:

- All MBSFN users reside in the center cell (UE drop location cells = 1).

- All MBSFN users reside in the area included by the inner 1 ring (UE drop location cells = 7).
- All MBSFN users reside in the area included by the inner 2 ring (UE drop location cells = 19).
- …
- All the infinite cells of the topology contain MBSFN users (UE drop location cells = infinite, i.e. number of cells >> 721 or number of cell rings >> 15).

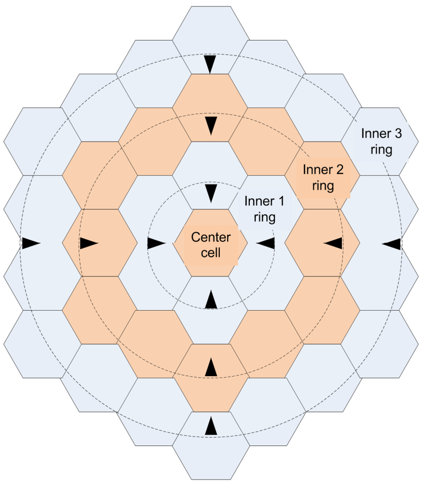

Figure 2. Topology under examination.

The performance of the MBSFN increases rapidly when rings of neighboring cells outside the "UE drop location cells" area assist the MBSFN service and transmit the same MBSFN data. More specifically according to [6] and [9], even the presence of one assisting ring can significantly increase the overall spectral efficiency. Moreover, we assume that a maximum of 3 neighboring rings outside the "UE drop location cells" can transmit in the same frequency and broadcast the same MBSFN data (assisting rings), since additional rings do not offer any significant additional gain in the MBSFN transmission [6], [9]. Our goal is to examine the number of neighboring rings that should be transmitting simultaneously with the UE drop location cells in order to achieve the highest gain possible, in terms of overall packet delivery cost. For this purpose we define the following three MBSFN deployments (where "A" stands for an Assisting ring and "I" for an Interference ring, i.e.: a ring that does not participate in the MBSFN transmission):

- **AII**: The first ring around the UE drop location cells, contributes in the MBSFN transmission, the second and third rings act as interference.
- **AAI**: The first and the second ring around the UE drop location cells assist in the MBSFN transmission, the third ring acts as interference.
- **AAA**: Each of the three surrounding rings of the UE drop location cells assists in the MBSFN transmission.

Depending on the number of the UE drop location cells, our target is to find which MBSFN deployment (AII, AAI, AAA) is more efficient in terms of overall cost.

The system simulation parameters that were taken into account for our simulations are presented in Table II. The typical evaluation scenarios used for LTE are macro Case 1 and macro Case 3 with 10 MHz bandwidth and low UE mobility. The propagation models for macro cell scenario are based on the Okamura-Hata model [4], [6].

TABLE II. SIMULATION PARAMETERS

Parameter	Units	Case 1	Case 3
Inter Site Distance (ISD)	m	500	1732
Carrier Frequency	MHz	2000	
Bandwidth	MHz	10	
Penetration Loss (PL)	dB	20	
Path Loss	dB	Okumura-Hata	
Cell Layout		Hexagonal grid, 3 sectors per site, Infinity rings	
Channel Model		3GPP Typical Urban (TU)	
# UE Rx Antennas		2	
UE speed	Km/h	3	
BS transmit power	dBm	46	
BS # Antennas		1	
BS Ant. Gain	dBi	14	

B. *Air Interface Cost*

In this section the transmission cost over the air interface is defined for different network topologies, user distributions and MBSFN deployments. Figure 3 depicts the resource efficiency of SFN transmission mode (i.e. the spectral efficiency of the SFN transmission normalized by the fraction of cells in the SFN area containing UEs) as the number of UE drop location cells increases, for the 3 different MBSFN deployments (AII, AAI, AAA) presented in the previous paragraph. More specifically, Figure 3(a) presents the way the resource efficiency changes with the number of UE drop location cells for a macrocellular Case 1 and Figure 3(b) for a macrocellular Case 3 environment [6], [9].

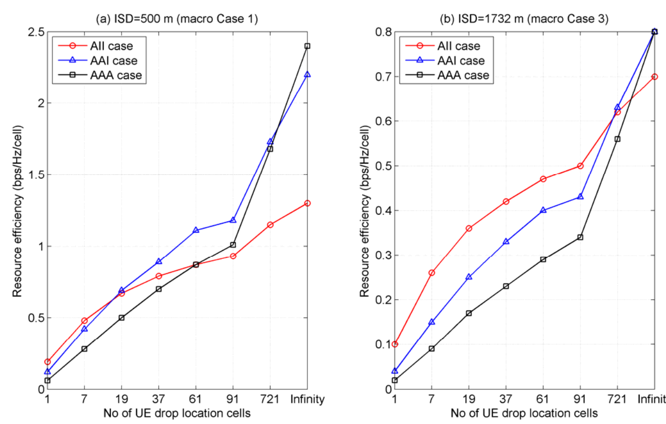

Figure 3. Resource efficiency vs. number of UE drop location cells for: (a) ISD = 500m (macro Case 1), (b) ISD = 1732m (macro Case 3).

From Figure 3(a), we observe that when all users are distributed in the center cell, the resource efficiency for AAA is 0.06, for AAI 0.12 and for AII 0.19. As a result, when all the MBSFN users reside in the center cell, AII is the best deployment. Similarly, if the number of UE drop location cells is equal to 19, the resource efficiency for AAA deployment is 0.50, for AAI 0.69 and finally for AII 0.67. Hence, for this case, AAI is the best deployment in terms of resource efficiency. Similar results can be extracted from Figure 3(b) that corresponds to the macro Case 3. However, we have to mention that in the above mentioned examples, the best deployment was selected based only on the air interface performance. Next in our analysis, we will present an alternative/improved approach that selects the best MBSFN deployment based on the overall cost.

To define the telecommunication cost over the air interface, we used the resource efficiency from Figure 3. From Figure 3 we observe that the maximum resource efficiency is 2.40 for macro Case 1 and 0.8 for macro Case 3. These maximum values appear when the users are located in an infinite ring topology. In our analysis, we define as resource efficiency percentage (*RE_percentage*) the fraction of current deployment resource efficiency to the maximum SFN resource efficiency.

$$RE\_percentage = \frac{\text{Resource efficiency of current deployment}}{\text{Max SFN resourse efficiency}} \quad (1)$$

The percentage indicates the quality of the resource efficiency our current deployment achieves for the macrocellular Case 1 or Case 3, compared to the maximum resource efficiency that can be achieved in Case 1 or Case 3 respectively.

Then, we define the cost of a single packet delivery over the air interface (D_{Uu}) as follows:

$$D_{Uu} = \frac{1}{RE\_percentage} \quad (2)$$

This means that as the resource efficiency of a cell increases, the *RE_percentage* increases too, which in turn means that the cost of packet delivery over the air interface decreases. On the other hand, if the resource efficiency of a cell decreases the equivalent transmission cost increases. Therefore, if a deployment X has worse spectral efficiency than a deployment Y, this means that a higher transmission cost for packet delivery should be defined for deployment X than in Y.

Finally, the total telecommunication cost for the transmission of the data packets over Uu interface is derived from equation 3, where N_{eNB} represents the number of e-NBs that participate in MBSFN transmission, N_p the total number of packets of the MBSFN session, and D_{Uu} is the cost of the delivery of a single packet over the Uu interface.

$$C_{Uu} = D_{Uu} \cdot N_p \cdot N_{eNB} \quad (3)$$

C. Cost over M1 Interface

M1 interface uses IP multicast protocol for the delivery of packets to e-NBs. In multicast, the e-MBMS GW forwards a single copy of each multicast packet to those e-NBs that participate in MBSFN transmission. After the correct multicast packet reception at the e-NBs that serve multicast users, the e-NBs transmit the multicast packets to the multicast users via MTCH transport channels. The total telecommunication cost for the transmission of the data packets over M1 interface is derived from equation 4.

$$C_{M1} = D_{M1} \cdot N_P \cdot N_{eNB} \quad (4)$$

The cost of the delivery of a single packet over the M1 interface is given by equation 5 [10]:

$$D_{M1} = \frac{l_{M1}}{k_{M1}} \quad (5)$$

where l_{M1} is the number of hops between the nodes connected by M1 interface and k_{M1} represents the profile of the M1 interface in terms of link capacity [10]. In general, a higher capacity link in M1 results in a higher value of k_{M1}. According to equation 5, a high value of k_{M1} corresponds to a low packet delivery cost over M1 and a small number of hops corresponds to a low packet delivery cost as well.

D. Synchronization Cost

In order to implement a SFN, each of the transmitting cells should be tightly time-synchronized and use the same time-frequency resources for transmitting the bit-identical content. The overall user plane architecture for content synchronization is depicted in Figure 4.

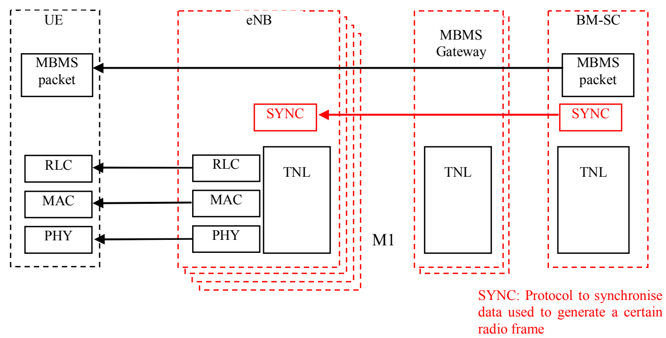

Figure 4. Content synchronization in MBSFN.

The SYNC protocol layer is defined on transport network layer to support content synchronization. It carries additional information that enables e-NBs to identify the timing for radio frame transmission and detect packet loss. Every e-MBMS service uses its own SYNC entity. The SYNC protocol operates between e-BM-SC and e-NB. As a result of synchronization, it is ensured that the same content is sent over the air to all UEs [3].

The e-BM-SC should indicate the timestamp (*T*) of the transmission of the first packet of a burst of data (block of packets) by all e-NBs and the interval between the radio transmissions of the subsequent packets of the burst as well. Since the synchronization protocol has not yet been standardized and many alternative protocols have been proposed [11], we assume that the transmission timestamp of the first packet of a burst of data is sent before the actual burst in a separate Packet Data Unit (PDU). When time *T* is reached, the e-NB buffer receives another value of *T* and new packet data which correspond to the next burst. All in all, in this case the transmission timing for subsequent bursts is implicitly determined by the size and the number of previous packets [11]. This in turn means that the synchronization cost depends on the total numbers of multicast bursts/packets per MBSFN session. The total telecommunication cost for the transmission of the synchronization packets is derived from the following equation where D_{M1} is the cost of the delivery of a single packet over the M1 interface and N_{p_burst} is the mean value of the number of packets transmitted each time in the sequential bursts of the MBSFN session.

$$C_{SYNC} = \frac{N_P}{N_{p\_burst}} \cdot D_{M1} \cdot N_{eNB} \quad (6)$$

E. Polling Cost

To determine which cells contain users interested in receiving a MBSFN service, we assume that a polling procedure is taking place. In contrast to counting procedure used in UMTS MBMS, where the exact number of MBMS users was determined, with polling we just determine if the cell contain at least one user interested for the given service.

The e-NBs initiate the detection procedure by sending a UE feedback request message on MCCH. The cost of sending this request message corresponds to the cost of polling procedure at e-NB (D_{p_eNB}). The message includes the MBMS service ID that requires the user feedback and a "dedicated access information" (in the form of a particular signature sequence) that is to be used for the user feedback by the UEs. After receiving the feedback request message, the UEs which are interested in receiving the particular MBMS service, respond to the request by sending a feedback message using the allocated "dedicated access resources" over non-synchronous Random Access Channel (RACH).

The e-NB receives the feedback from the UEs in the form of signature sequence. If energy is detected corresponding to the known signature sequence, this indicates that at least one user in the coverage area of the e-NB is interested in or activated the particular MBMS service. This information (packet) is sent to the MCE over M2 interface which in turn estimates which cells contain MBMS users interested for the given MBMS service [12].

The total cost associated to the polling procedure is derived from equation 7, where N_{eNB} represents the number of e-NBs that participate in MBSFN transmission, N_{cell} is the total number of e-NBs in the topology and D_{M2} is the cost of the delivery of a single packet over the M2 interface.

$$C_{Polling} = D_{p\_eNB} \cdot N_{cell} + D_{M2} \cdot N_{eNB} \quad (7)$$

F. Total Telecommunication Cost

Based on the analysis presented in the previous paragraphs, the total telecommunication cost of the MBSFN delivery scheme is derived from the following equation.

$$C_{MBSFN} = C_{Uu} + C_{M1} + C_{SYNC} + C_{Polling} = \\ = \left(D_{Uu} + D_{M1} + \frac{D_{M1}}{N_{p\_burst}} \right) \cdot N_p \cdot N_{eNB} + \left(D_{p\_eNB} \cdot N_{cell} + D_{M2} \cdot N_{eNB} \right) \quad (8)$$

IV. Results

Having analyzed the costs of the MBSFN delivery scheme, we try to evaluate the cost of each of the MBSFN deployments (AAA, AAI, AII) for different user distributions. The topology we used is the one described in Section III.A. Moreover, in Table III we present the chosen values for the simulation parameters, according to [10].

TABLE III. CHOSEN VALUES FOR THE SIMULATION PARAMETERS

N_p	N_{p_burst}	k_{M1}	l_{M1}	k_{M2}	l_{M2}
10000	N_p/100	0.5	3	0.5	1

Figure 5, depicts the normalized total cost of the deployments AII, AAI, AAA as the number of packets of the MBSFN service increases from 0 to 10000 in a macro Case 1 environment. More specifically, Figure 5(a) refers to the case where the number of UE drop location cells is 7. For this case we observe that as the number of packets increases, the total cost increases as well. This increment is mainly caused by the simultaneous increment of the air interface cost. We also observe that AII is the most efficient deployment for transmission in terms of total cost. On the other hand, Figure 5(b) depicts the total cost of AAA, AAI, AII when the number of UE drop location cells is 91. For this case, we observe that AAI is the most efficient deployment. Based on the above, it is clear that the way the users are distributed in the topology has a great impact on the selection of the most cost efficient MBSFN deployment. This observation leads us to determine the appropriate switching points (number of UE drop location cells) between the 3 different deployments.

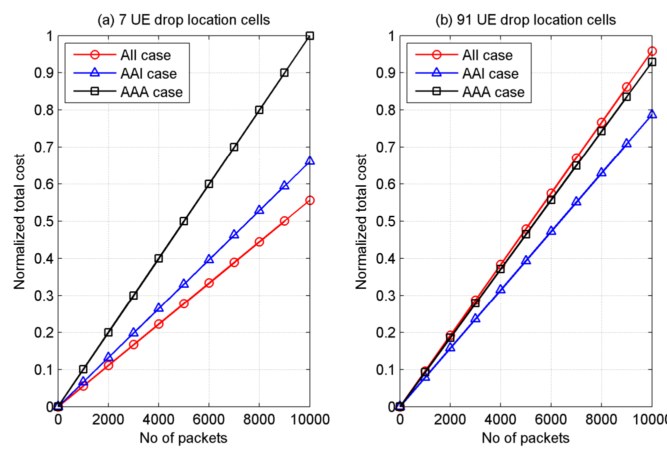

Figure 5. MBSFN cost for AII, AAI, AAA vs. number of packets for macro Case 1 when UE drop location cells is equal to: (a) 7 and (b) 91.

More specifically, Figure 6 depicts the total cost of the SFN transmission for the 3 different deployments as the number of UE drop location cells increases, when ISD = 500m (macro Case 1). We observe that for the first 3 user distributions (UE drop location cells = 1, 7, 19), the AII deployment ensures the lowest cost. For UE drop location cells 37, 61, 91 and 721 cells, AAI is the most efficient deployment. Finally, for the case of the MBSFN transmission where the users are residing in infinite cells, the AAA deployment is more efficient than the other two deployments, since it results in a lower overall cost.

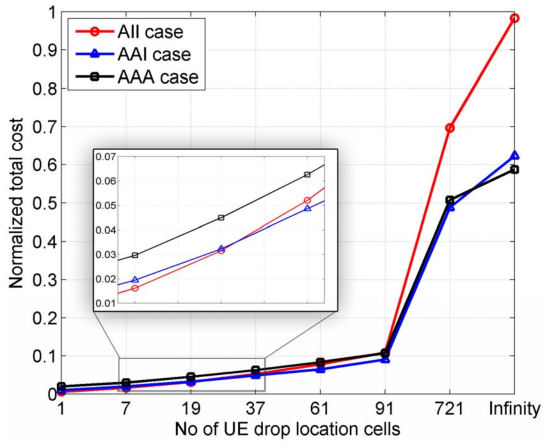

Figure 6. MBSFN cost for AII, AAI, AAA vs. number of UE drop location cells when ISD = 500m (macro Case 1).

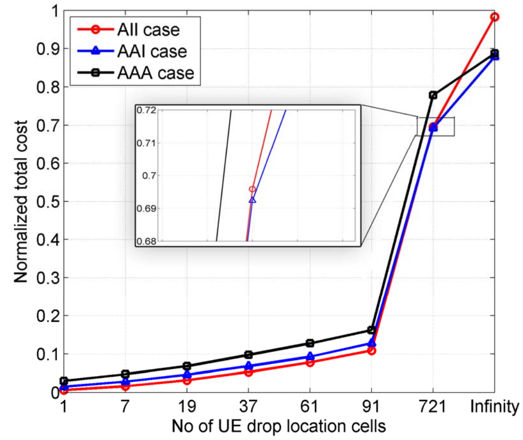

Figure 7. MBSFN cost for AII, AAI, AAA vs. number of UE drop location cells when ISD = 1732m (macro Case 3).

Generally, it is necessary to switch between the 3 MBSFN deployments, when the number of UE drop location cells increases, so as to achieve the lowest possible transmission cost. More specifically, as the number of UE drop location cells increases, the most efficient deployment for the delivery of the MBSFN data, switches from AII, to AAI and finally to AAA when the number of cells that have users interested in the MBSFN service approaches infinity. This switching can save resources both in the core network and the air interface. For example, in the case of 721 UE drop location cells, we observe that the normalized total cost when AII is used is 0.6967. However, when AAI is used the total normalized cost is 0.4879. Therefore, the usage of AAI instead of AII can decrease the total telecommunication cost by (0.6967-0.4879) / 0.6967 = 29.96%.

Additionally, Figure 7 depicts the total cost of the SFN transmissions of the 3 different deployments (AII, AAI, AAA) for the different user distributions when ISD = 1732m (macro Case 3). We observe that for the first 6 user distributions (UE drop location cells = 1, 7, 19, 37, 61 and 91) the most efficient MBSFB deployment is AII. For UE drop location cells equal to 721, AAI is the most efficient deployment and finally, for the case where the users reside in infinite cells, AAI results in a lower transmission cost and should be preferred over the other two MBSFN deployments.

V. CONCLUSIONS AND FUTURE WORK

In this paper, an analytical approach is proposed to evaluate and validate the performance of a MBSFN LTE network. The proposed evaluation approach is based on the calculation of the total telecommunication cost (including packet delivery cost and cost for controlling procedures) of a MBSFN transmission, considering different network topologies, MBSFN deployments and user distributions. By using this evaluation procedure, we estimate how many neighboring rings of the cells that actually contain users interested in a MBSFN service, should be in the same MBSFN area and thus transmitting in the same frequency, in order to achieve high SFN gains with the lowest possible telecommunication cost.

Based on the above estimation, the step that follows this work is to design an algorithm responsible for selecting in real time the most efficient MBSFN deployment scheme for the transmission of the multimedia data, by taking into account user mobility which enforces the network to perform continuous MBSFN area updates.

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