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Adaptive handover scheme for evolved multimedia broadcast multicast services in long-term evolution networks

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Abstract: The evolved multimedia broadcast multicast services (E-MBMS) can bring television (TV) services to a small mobile phone. The E-MBMS has been proposed in the third generation partnership project long-term evolution standardisation to support both normal mobile phone and mobile TV capabilities on a single device. As the E-MBMS delivers the same content simultaneously to multiple E-MBMS users sharing the same subframe in the multicast broadcast single frequency network (MBSFN) area and has the benefit of short handover latency when handover occurs within the MBSFN area; it is important to increase the number of E-MBMS users to be supported within the MBSFN area in order to achieve better performance in terms of spectral efficiency and handover latency. To obtain the advantages mentioned above, the proposed adaptive handover scheme increases the handover hysteresis margin (HM) when an E-MBMS user moves from the serving MBSFN area to the target non-MBSFN area and decreases the handover HM when an E-MBMS user travels from the serving non-MBSFN area to the target MBSFN area. Simulation results show that the spectral efficiency can be improved by increasing the number of E-MBMS users in the MBSFN area. Also, it is shown that the lower handover latency can be achieved by reducing the additional handover signalling message exchanges.

1 Introduction

Recently, with the rapid growth of the mobile phones like the smartphone, many mobile users want to watch television (TV) programmes on their mobile phones. Some solutions to this need were digital video broadcasting-handheld (DVB-H), digital multimedia broadcasting, media forward link only and so on. As opposed to these technologies many mobile devices have both normal mobile phone and mobile TV capabilities, multimedia broadcast multicast services (MBMS) in the third generation partnership project (3GPP) networks supports both mobile phone and mobile TV capabilities on a single chip without any large extra cost.

Especially, mobile video multicast, or mobile TV, such as live streaming, near-live content and VoD services is dramatically expanding and will be planned to become the killer application in the near future. From the mobile network operators' point of view, a big benefit of the video multicast over long-term evolution (LTE) networks is that the bandwidth consumption is not dependent on the number of simultaneous users because the same content can be received by many users simultaneously. From the mobile users' point of view, they will to be able to use the video multicast anytime, anywhere. Also, as the LTE technology embeds the video multicast capability, there is no need for any additional infrastructure apart from the LTE networks. For all these reasons, the LTE multicast will help mobile network operators dramatically who will benefit from new revenue opportunities. Therefore, mobile network operators are being challenged by the necessity of providing the mobile users with the video multicast over LTE networks and in turn are pushing the manufacturing industry to develop new and efficient mobile devices for delivering the video multicast over LTE networks. As a result, LTE multicast technology will satisfy the huge demand for mobile video multicast and rapidly improve the quality of the video multicast service for mobile users [1, 2].

The MBMS was first defined as point-to-multipoint (PTM) services for universal mobile telecommunication system (UMTS) networks, while its next version, evolved multimedia broadcast multicast services (E-MBMS), making use of the LTE networks. The E-MBMS has been standardised in various groups of 3GPP LTE which has progressed from Release 6 to Release 11 [3–7]. Therefore, E-MBMS will have a good prospect of being the core standardisation of the mobile TV defined as multimedia services delivered over IP-based wire and wireless converged networks.

The E-MBMS in LTE networks can be supported by point-to-point (PTP) services and PTM services. PTP E-MBMS services mean the transmission of E-MBMS data from a single source to single destination as the traditional unicast transmission, while PTM E-MBMS services imply the transmission of E-MBMS data from a single source to multiple destinations. Also, PTM E-MBMS transmission can be implemented by single cell-based E-MBMS services simultaneously transmitted within a single cell and a multicast broadcast single frequency network (MBSFN)-based E-MBMS services simultaneously transmitted from multiple time-synchronised cells.

Single-cell-based E-MBMS services are identical to MBMS services in UMTS networks. However, LTE networks provide both single cell-based E-MBMS services and multicell-based E-MBMS services, also known as MBSFN-based E-MBMS services. Although there have been a lot of studies which deal with MBMS handovers in single cell-based MBMS services of UMTS networks [8–10], there has been no research to address the E-MBMS handover in MBSFN-based E-MBMS services of LTE networks. Also, it is known that the MBSFN-based E-MBMS services can achieve much more spectral efficiency than the single cell-based E-MBMS services because E-MBMS users can exploit macro diversity by combining the same signals from multiple evolved NodeBs (eNBs) [5–7, 11]. Because of this reason, it is advantageous for more E-MBMS users to be encouraged to be served within the MBSFN area. Therefore, this paper proposes an adaptive handover hysteresis scheme in LTE networks for allowing more E-MBMS users to go preferentially into the MBSFN area if possible. To that end, the proposed adaptive handover hysteresis scheme adaptively adjusts the handover hysteresis margin (HM) which is an important handover initiation parameter to decide the moment triggering the handover procedure while considering the moving direction of E-MBMS users. Specifically, the proposed scheme chooses the larger HM if an E-MBMS user moves from the serving MBSFN area to the target non-MBSFN area. As a result, it is very likely that only few E-MBMS users in the MBSFN area can move into the non-MBSFN area. On the other hand, the proposed scheme chooses the smaller HM if an E-MBMS user travels from the serving non-MBSFN area to the target MBSFN area. This smaller margin tries to allow a lot of E-MBMS users in the non-MBSFN area to move into the MBSFN area. In this case, note that any additional handover signalling messages are not required if an E-MBMS user with the same content already existed inside the same MBSFN area [6, 12]. Consequently, the proposed scheme improves the spectral efficiency by increasing the number of E-MBMS users in MBSFN area. Also, it reduces the handover latency by decreasing the number of the handover message exchanges bringing about the long latency.

The rest of this paper is organised as follows. In Section 2, an overview of E-MBMS in the 3GPP LTE networks is presented. Section 3 describes a proposed adaptive handover procedure, a fixed handover hysteresis scheme and a proposed adaptive handover hysteresis scheme for E-MBMS services between the MBSFN area and the non-MBSFN area. Section 4 explains a simulation environment. Simulation results are discussed in Section 5. Finally, we conclude this paper in Section 6.

2 E-MBMS in the 3GPP LTE networks

Fig. 1 shows an E-MBMS logical architecture in the 3GPP LTE networks [6, 7]. In Fig. 1, the multicell/multicast coordination entity (MCE) is a logical entity whose functions are admission control and allocation of radio resources used by all eNBs for E-MBMS. In OFDM-based LTE networks, the ten subframes are included in a radio frame with the duration of 10 ms. The subframes are reserved for all the physical multicast transport channels (PMCHs) in the physical layer, which are mapped from the multicast control channel (MCCH) and the multicast traffic channel (MTCH) in the media access control (MAC) layer of an MBSFN area where the MCCH and the MTCH are the logical channels that carry information of E-MBMS services. Therefore, LTE E-MBMS services are multiplexed in time inside the MBSFN subframes [13]. A subframe can be allocated to an E-MBMS user for the E-MBMS services. Mobility management entity (MME) manages the location and paging process of 3GPP LTE networks as a control-plane element for mobility management and connection management. The E-MBMS gateway (GW), which consists of E-MBMS user plane (UP) and E-MBMS control plane (CP), is a logical entity that is present between the broadcast multicast service centre (BM-SC) and eNBs. Its principal function is to broadcast the packets to all eNBs for E-MBMS and to perform E-MBMS session control signalling (Session Start/Stop) towards the eNB via MME and MCE. Sm is the reference point for the CP between MME and E-MBMS GW. The BM-SC node is responsible for authorisation and authentication of content provider, charging, and overall data flow through CN. SGmb supports the E-MBMS signalling between BM-SC and E-MBMS GW while the SGi-mb supports the E-MBMS traffic plane between BM-SC and E-MBMS GW. M1 is a pure UP interface, so the eNBs are connected to E-MBMS GW through the UP interface M1. Also two CP interfaces M2 and M3 are defined. Concretely speaking, the M1 interface makes use of IP multicast protocol for the delivery of packets from E-MBMS GW to eNBs. The M2 interface is used by the MCE to provide the eNB with E-MBMS session management and radio configuration. The M3 interface supports the E-MBMS session control signalling for E-MBMS session management such as session initiation and termination between MME and MCE.

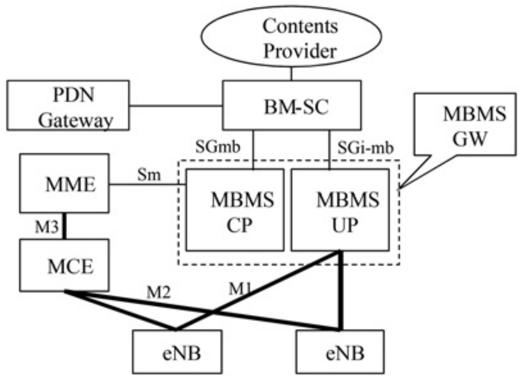

Fig. 1 *E-MBMS logical architecture*

3 Handover scheme for E-MBMS handover between the MBSFN area and the non-MBSFN area

3.1 Proposed adaptive handover procedure for E-MBMS handover between the MBSFN area and the non-MBSFN area

This section presents in more detail the proposed handover scheme. 3GPP LTE supports currently only hard handover scheme and hard handover for E-MBMS is divided into three phases. The phase 1 is handover within the

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non-MBSFN area for the PTP E-MBMS services by the unicast transmission. The phase 2 is handover within the single cell E-MBMS area for the PTM E-MBMS services by the multicast transmission and is the same as the handover for MBMS services in UMTS networks [8–10]. The phase 3 is handover within the MBSFN area for the PTM E-MBMS services by the multicast transmission in LTE networks [5]. Here, the single cell-based E-MBMS (the phase 2) does not utilise any macro diversity gain but the MBSFN-based E-MBMS (the phase 3) has a macro diversity gain [6]. As the macro diversity gain results in a significant system performance enhancement for the E-MBMS services, LTE basically supports MBSFN-based E-MBMS services that PTM E-MBMS services can be used in combination with MBSFN consisting of a group of multiple cells. Thus, in this paper, the phase 2 is not considered. Under this assumption supporting the mixed configuration of the MBSFN area for the PTM E-MBMS services and the non-MBSFN area for the PTP E-MBMS services [14–16], the handover of E-MBMS users between the MBSFN area and the non-MBSFN area should be considered as a new innovative and significant feature. As it has fully different characteristics compared to the existing handover scheme because of its structural difference, the handover scheme in the mixed configuration of the MBSFN area and the non-MBSFN area has to be differently approached for its performance enhancement. To the best of our knowledge, there has been no study on the MBSFN-based handover of the E-MBMS users between the MBSFN area and the non-MBSFN area. To address this problem, in this paper we introduce a novel adaptive handover hysteresis scheme which encourages more E-MBMS users to be supported in MBSFN area with the PTM E-MBMS services as a way to increase the spectral efficiency by allowing the same subframe to be shared in an economical way. As a result, the proposed scheme can improve the spectral efficiency and the handover latency because it allows the limited subframes to be efficiently saved by allocating duplicately the same subframe to multiple E-MBMS users with the same content in the MBSFN area instead of allocating the same number of subframes as the number of E-MBMS users.

Fig. 2 shows an example of a scenario for the proposed adaptive handover hysteresis scheme which deals with handover of the E-MBMS user between the MBSFN area for the PTM E-MBMS services by the multicast transmission and the non-MBSFN area for the PTP E-MBMS services by the unicast transmission. As shown in Fig. 2, handover operation in the proposed scheme is divided into two handover scenarios depending on the handover direction. One is the handover moving from the serving MBSFN area to the target non-MBSFN area. The other is the handover moving from the serving non-MBSFN area to the target MBSFN area. As illustrated in Fig. 3, the former requires any additional handover signalling messages causing the long latency like E-MBMS registration/deregistration and session start/stop procedures towards the eNB via MME and BM-SC every handover operation, while the latter and the handover within the same MBSFN area are operated without any additional handover signalling messages bringing about the long latency towards the eNB via MME and BM-SC [6, 12].

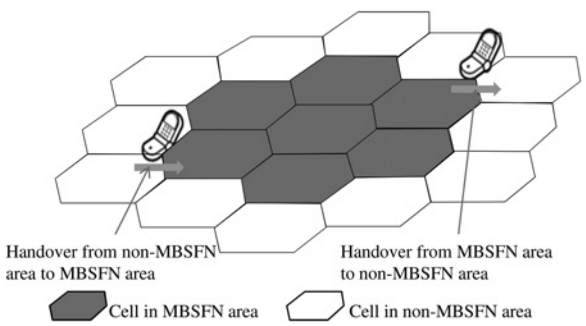

Fig. 2 *Example of a scenario for the proposed adaptive handover hysteresis scheme*

In case of the handover moving from the serving non-MBSFN area to the target MBSFN area, whenever such a handover generates, the existence of E-MBMS user with the same content will be checked in the target MBSFN area. At that time, if an E-MBMS user with the same content already existed, the newly generated E-MBMS user shares the same subframe inside the same MBSFN area, so that it does not require any additional handover signalling messages creating the long latency such as E-MBMS Registration and Session Start messages towards the eNB via MME and BM-SC. Thus, to reduce the handover latency, it is required to prevent the handovers from the serving MBSFN area to the target non-MBSFN area.

3.2 Handover initiation method for E-MBMS services between the MBSFN area and the non-MBSFN area

The handover initiation is a process determining when to start a handover based on received signal strengths (RSSs) from the serving eNB and target eNBs. When the RSSs are reported through Measurement Report message every measurement report period as illustrated in Fig. 3 and the target eNB's RSS exceeds the serving eNB's RSS, handover is requested [17]. As the handover's performance evaluation depends on various initiation criteria, this paper considers the handover initiation method which combines three parameters such as threshold, HM, and time-to-trigger (TTT) values together.

In case of threshold parameter, the serving eNB's RSS has to be lower than a given threshold value (Th in Figs. 4 and 5) and the target's RSS has to be higher than the serving eNB's RSSs as

$$\mathrm{RSS}_{\text{Serving eNB}} < \mathrm{Th} \text{ and } \mathrm{RSS}_{\text{Target eNB}} > \mathrm{RSS}_{\text{Serving eNB}} \quad (1)$$

In case of HM parameter, the difference between the target eNB's RSS and the serving eNB's RSS has to be more than a given HM value (HM in Figs. 4 and 5) like

$$\mathrm{RSS}_{\text{Target eNB}} - \mathrm{RSS}_{\text{Serving eNB}} > \mathrm{HM} \quad (2)$$

In case of TTT parameter, the time interval (Time $(\mathrm{RSS}_{\text{Target eNB}} - \mathrm{RSS}_{\text{Serving eNB}})$) between the target eNB's RSS and the serving eNB's RSS has to be held longer than a given TTT value (ΔT in Figs. 4 and 5) as

$$\mathrm{Time}(\mathrm{RSS}_{\text{Target eNB}} - \mathrm{RSS}_{\text{Serving eNB}}) > \Delta T \quad (3)$$

Besides, the time interval should satisfy the condition that the target eNB's RSS is consistently higher than the serving eNB's RSS during the period. HM is regarded as an

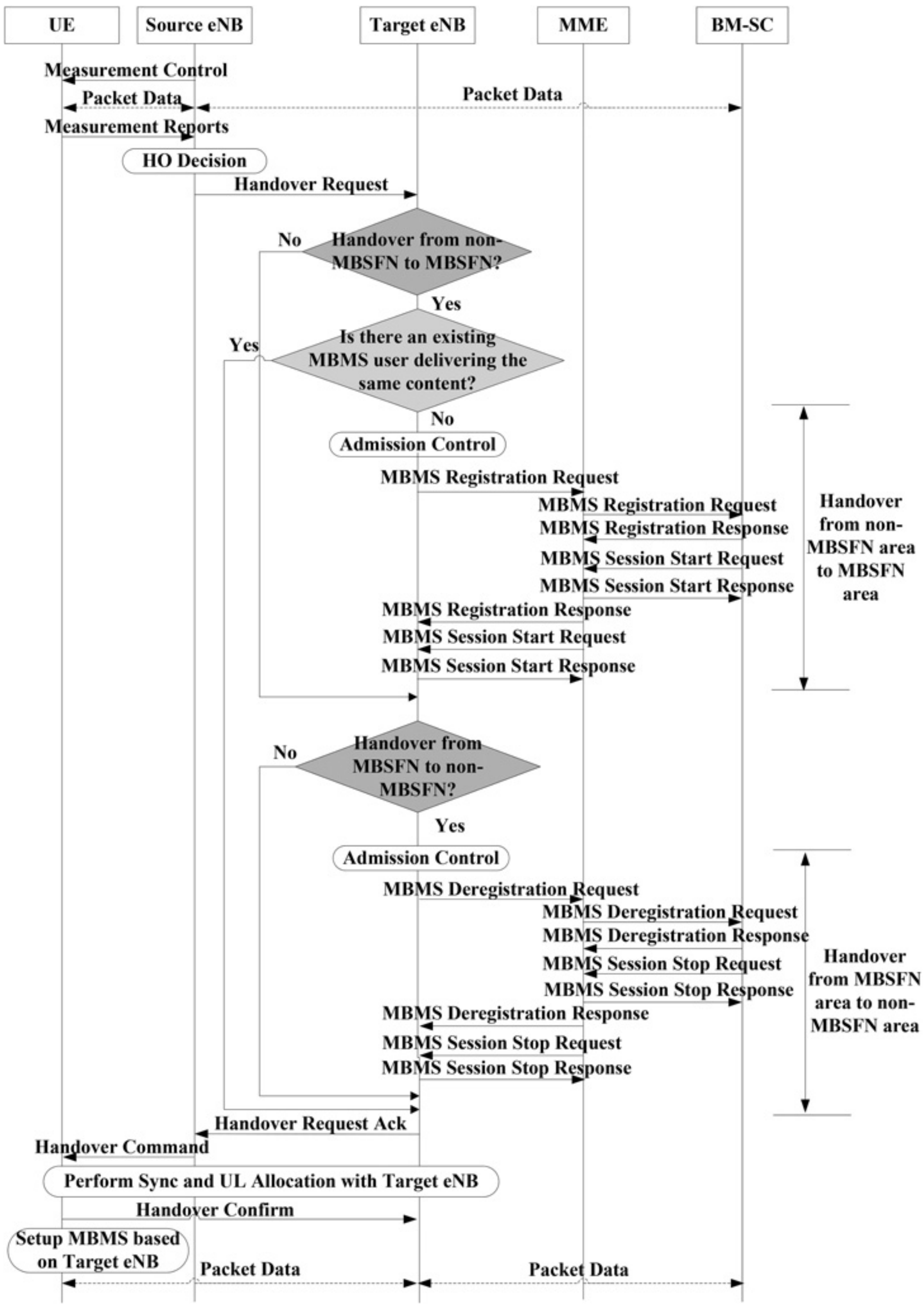

Fig. 3 *Proposed adaptive handover procedure for E-MBMS handover between the MB-SFN area and the non-MBSFN area*

important factor among the handover initiation parameters. The HM can be defined as the RSS difference between the serving and target eNBs. Fig. 4 shows an example of applying the fixed handover hysteresis for E-MBMS handover between the MBSFN area and the non-MBSFN area. The existing handover hysteresis scheme for E-MBMS services between the MBSFN area and the non-MBSFN area can adopt mostly a fixed HM value like Fig. 4 for easy implementation. Therefore, the handover margin in the fixed handover hysteresis scheme for E-MBMS services is given as follows

$$\mathrm{HM} = \mathrm{HM}_{\mathrm{Basic}} \tag{4}$$

Also, $\mathrm{RSS}_{\mathrm{Target\ eNB}} - \mathrm{RSS}_{\mathrm{Serving\ eNB}} > \mathrm{HM}$ satisfying both the (1) and (3) is required for the successful handover initiation. The radio resource control (RRC) protocol in the eNB makes a handover decision when $\mathrm{Time}(\mathrm{RSS}_{\mathrm{Target\ eNB}} - \mathrm{RSS}_{\mathrm{Serving\ eNB}})$ is held more than ΔT after the handover initiation [18].

3.3 Proposed adaptive handover hysteresis scheme for E-MBMS services between the MBSFN area and the non-MBSFN area

When E-MBMS handover is generated between the MBSFN area and the non-MBSFN, the existing handover scheme does not take into account the existence of the MBSFN area. Therefore, a new MBSFN-based handover scheme considering the coexistence of the MBSFN area and the non-MBSFN area is required. Also, although there have been many studies done on MBMS handover in the single cell-based MBMS services [8–10], there have been no published studies about MBSFN-based handover scheme

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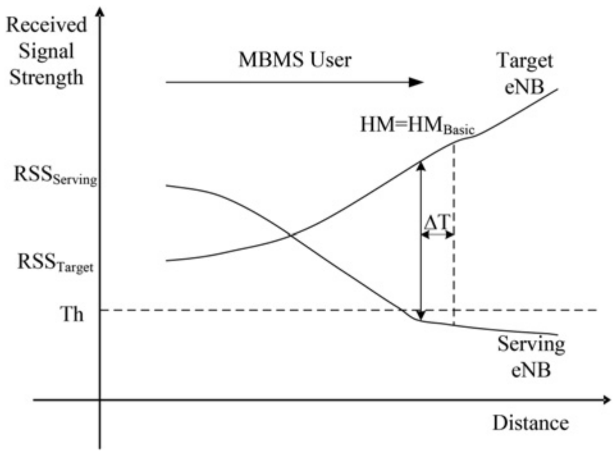

Fig. 4 *Example of applying the fixed handover hysteresis scheme for E-MBMS handover between the MBSFN area and the non-MBSFN area*

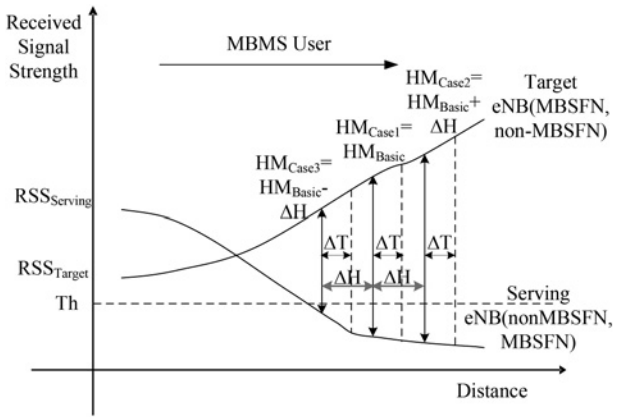

Fig. 5 *Example of applying the proposed adaptive handover hysteresis scheme for E-MBMS handover between the MBSFN area and the non-MBSFN area*

considering the effect of the handover initiation between the MBSFN area and the non-MBSFN area until now. It is effective that E-MBMS users in the MBSFN area are operated by PTM E-MBMS services that E-MBMS data packets are transmitted simultaneously from a single source to multiple destinations. In other words, as E-MBMS users sending the same content in the MBSFN area share the same subframe, the limited subframes can be efficiently utilised by allocating duplicately the same subframe to multiple E-MBMS users even if their number increases. In order to gain a competitive advantage by more E-MBMS users staying within the MBSFN area, the handover HM can be adaptively adjusted according to the handover direction.

Going into more detailed description of the proposed scheme, the larger the HM value the smaller is the number of handovers. On the other hand, the smaller the HM value, the larger is the number of handovers. From these facts, the proposed adaptive handover hysteresis scheme has the larger handover HM with the aim of decreasing the number of handovers when an E-MBMS user handovers from the serving MBSFN area to the target non-MBSFN area and the smaller handover HM with the objective of increasing the number of handovers when an E-MBMS user handovers from the serving non-MBSFN area to the target MBSFN area. The proposed scheme can stimulate more E-MBMS users to be moved into the MBSFN area, so that it provides much better spectral efficiency and handover latency performance because the increased E-MBMS users sending the same content in the MBSFN area share the same subframe regardless of the number of E-MBMS users. Additionally, if there is no E-MBMS user in the non-MBSFN area owing to the active movement of more E-MBMS users from the serving non-MBSFN area to the target MBSFN area by the proposed scheme, the corresponding subframes returned from the moved E-MBMS users can be reused for other non-E-MBMS users that do not receive a certain E-MBMS service in the non-MBSFN area. For these effects, this paper introduces a handover hysteresis scheme with the adaptive HM which consists of three cases according to the handover direction as shown in Fig. 5.

The first case is to determine the magnitude of HM for the handover generated inside the same MBSFN area. This gives a short handover latency because all E-MBMS users within the MBSFN area exchange only the handover signalling message between E-MBMS user and eNB without any additional handover signalling message exchanges towards the eNB via MME and BM-SC as shown in Fig. 3. Thus, the HM in the first case is almost equal to the HM in the existing handover hysteresis scheme. In consequence, if the existing fixed handover hysteresis scheme is used, the HM in the first case can be considered as the same value as (4), so is given by

$$\mathrm{HM}_{\mathrm{Case1}} = \mathrm{HM}_{\mathrm{Basic}} \tag{5}$$

Also, $\mathrm{RSS}_{\mathrm{Target\ eNB}} - \mathrm{RSS}_{\mathrm{Serving\ eNB}} > \mathrm{HM}_{\mathrm{Case1}}$ meeting (1) and (3) together is needed for the handover initiation.

The second case is to increase the HM with the purpose of reducing the number of the handover trials from the serving MBSFN area to the target non-MBSFN area. The increased HM prevents E-MBMS users in the MBSFN area from moving into the non-E-MBMS area, in reducing the number of the handover trials. As a result, the higher spectral efficiency can be achieved by the increase of E-MBMS users in the MBSFN area and the handover latency can be shortened by the decrease of the additional handover signalling message exchanges towards the eNB via MME and BM-SC in Fig. 3. The HM in the second case is formulated as follows

$$\mathrm{HM}_{\mathrm{Case2}} = \mathrm{HM}_{\mathrm{Basic}} + \Delta H \tag{6}$$

Also, $\mathrm{RSS}_{\mathrm{Target\ non\text{-}MBSFN}} - \mathrm{RSS}_{\mathrm{Serving\ MBSFN}} > \mathrm{HM}_{\mathrm{Case2}}$ satisfying both (1) and (3) is required to initiate handover, where the HM deviation (ΔH) provides a significant impact on the handover performance as an important factor which determines the magnitude of HM. Thus, this paper investigates the performance change according to its magnitude.

The third case is to decrease the HM with the aim of promoting the handover moving from the serving non-MBSFN area to the target MBSFN area. The decreased HM encourages E-MBMS users in the non-MBSFN area to move into the MBSFN area in order to increase the number of E-MBMS users supported within the MBSFN area. Even if the decreased HM increases the handover rate from the serving non-MBSFN area to the target MBSFN area, there is no increase of the handover latency because any additional handover signalling messages towards the eNB via MME and BM-SC are not required if E-MBMS user with the same content already existed inside the same MBSFN area as shown in Fig. 3. As a result, the third case provides greater spectral efficiency by the increase of E-MBMS users in the MBSFN area without the increase of the handover latency. The HM in the third case is given by

$$\mathrm{HM}_{\mathrm{Case3}} = \mathrm{HM}_{\mathrm{Basic}} - \Delta H \quad (7)$$

Also, $\mathrm{RSS}_{\mathrm{Target\ \ MBSFN}} - \mathrm{RSS}_{\mathrm{Serving\ \ non\text{-}MBSFN}} > \mathrm{HM}_{\mathrm{Case3}}$ meeting both (1) and (3) is required for the handover initiation.

After all, as the proposed scheme adaptively applies the HM value like (5)–(7) according to the handover direction, it can be called a kind of direction-based handover algorithm.

Fig. 6 shows the MBSFN area enlargement through the handover boundary displacement by the proposed scheme for E-MBMS handover between the MBSFN area and the non-MBSFN area. As shown in Fig. 6, when an E-MBMS user moves from non-MBSFN area to MBSFN area, handover margin is decreased from $\mathrm{HM}_{\mathrm{Basic}}$ to $\mathrm{HM}_{\mathrm{Basic}} - \Delta H$ so as to enlarge in MSFSN cell with respect to non-MBSFN cell. Also, when an E-MBMS user moves from MBSFN area to non-MBSFN area, handover margin is increased from $\mathrm{HM}_{\mathrm{Basic}}$ to $\mathrm{HM}_{\mathrm{Basic}} + \Delta H$ so as to enlarge in MSFSN cell with respect to non-MBSFN cell. It is clearly observed in Fig. 6 that the service area of MBSFN has been enlarged by the proposed adaptive handover scheme. In this paper, ΔH falls between 0 and ΔH_{max}. ΔH_{max} can be chosen as a value to maximise the performance gain such as spectral efficiency maximum and handover latency minimum. The displacement of handover margin from $\mathrm{HM}_{\mathrm{Basic}}$ to $\mathrm{HM}_{\mathrm{Basic}} + \Delta H_{\mathrm{max}}$ or $\mathrm{HM}_{\mathrm{Basic}} - \Delta H_{\mathrm{max}}$ represents that the handover boundary reaches up to the MBSFN cell boundary in the overlapped region of adjacent MBSFN and non-MBSFN cells. Eventually, it achieves the maximum enlargement of the MBSFN area [19, 20].

As a result, the proposed adaptive handover hysteresis scheme based on the 3GPP LTE networks is suggested to increase the number of E-MBMS users supported within the MBSFN area, so that it improves the performance of both the spectral efficiency and the handover latency compared to the existing single cell-based handover hysteresis scheme without considering the MBSFN feature. In addition, it is noted that larger ΔH can result in higher spectral efficiency and lower handover latency because it can reduce unnecessary handovers by adjusting accordingly the HM. From the following simulation results, we can study the effects on the spectral efficiency and the handover latency owing to the magnitude of ΔH.

Under the new cell structure of E-MBMS system where the MBSFN area and the non-MBSFN area coexist, the existing handover initiation by the single cell-based E-MBMS services brings about the spectral inefficiency and the long handover latency because it does not consider adaptive HM value adapting to the handover direction between the MBSFN area and the non-MBSFN area. For this reason, we introduce a new adaptive handover hysteresis scheme with the goal of increasing the number of E-MBMS users to be supported within the MBSFN area by encouraging E-MBMS users to handover from the serving non-MBSFN area to the target MBSFN area and discouraging E-MBMS

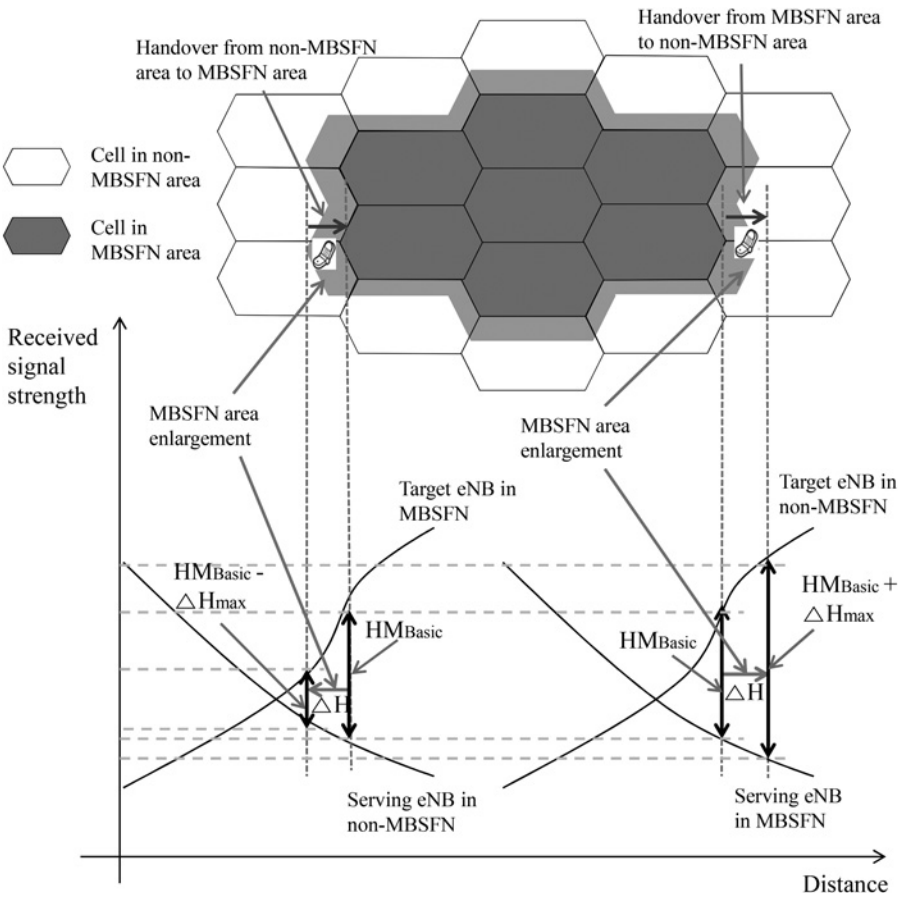

Fig. 6 *Handover boundary displacement by the proposed adaptive handover hysteresis scheme for E-MBMS handover between the MBSFN area and the non-MBSFN area*

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users to handover from the serving MBSFN area to the target non-MBSFN area. The proposed scheme treats a subject on the provision of E-MBMS services by giving handover priority to the MBSFN area with the PTM E-MBMS services. The comprehensive evaluation through simulation experiments under the environment where the MBSFN area and the non-MBSFN area coexist demonstrates the effectiveness and efficiency of the proposed scheme.

4 Simulation environment

Fig. 7 shows the topology for simulation. To examine simply the performance gain in the MBSFN transmission, as shown in Fig. 7, it is assumed that the E-MBMS users can be located in a constantly increasing area of cells in the topology with the 3 different MBSFN deployments such as MBSFN area size 1, MBSFN area size 7 and MBSFN area size 19 based on the 3GPP LTE downlink specifications defined in [21–23], where the MBSFN area size 1, MBSFN area size 7 and MBSFN area size 19 consist of MBSFN cell of 1, MBSFN cells of 7 and MBSFN cells of 19, respectively. Also, it is assumed that the outside of the MBSFN area is composed of the non-MBSFN cells. The PTM E-MBMS services are supported in MBSFN area and the PTP E-MBMS services are supported in non-MBSFN area. First, MBSFN area size 1 means that the first ring indicating the centre cell supports the MBSFN transmission while the second, third and fourth rings are operated as the unicast transmission. Second, MBSFN area size 7 means that the first and second rings indicating the centre cell and first-tier cells support the MBSFN transmission while the third and fourth rings are operated as the unicast transmission. Finally, MBSFN area size 19 means that the first, second and third rings indicating the centre cell, first-tier and second-tier cells support the MBSFN transmission while the fourth ring is operated as the unicast transmission. MBSFN area size can significantly affect the performance gain in the MBSFN transmission like the spectral efficiency and the handover latency for E-MBMS users [21, 22, 24]. Thus, it is easily forecasted that the increasing MBSFN area cells can significantly increase the overall spectral efficiency and decrease the overall handover latency. Table 1 shows the values of main parameters used for simulations [21–23].

The E-MBMS users in MBSFN area are multiplexed in time inside MBSFN subframes, while the E-MBMS users in non-MBSFN area are multiplexed with unicast services by the different channelisation codes. According to frame structure type 1 (FDD) of LTE E-MBMS, a subframe is

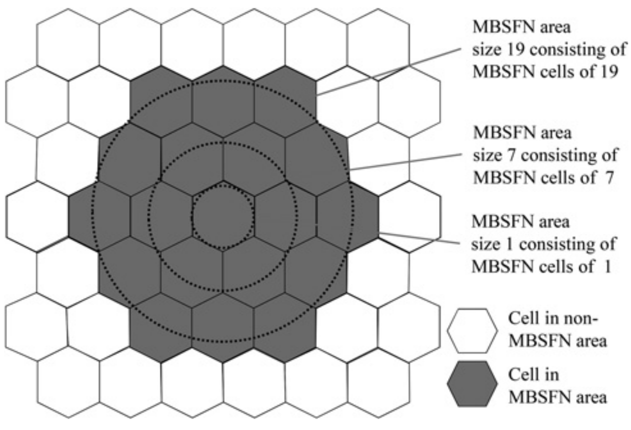

Fig. 7 *Three MBSFN deployments for simulation*

Table 1 System parameters

Parameter	Value
network layout	3-tier cell wrapping model
cell radius	1 km
cell bandwidth	5 MHz
peak data rate per cell	20 Mbps
total data rate of all cells	20 × 37 Mbps
transmit power of eNB	43 dBm
antenna type	Omni-direction
pass loss model	$128.1 + 37.6 log_{10}^{R}$, R in km
std. deviation for shadowing	6.5 dB
basic hysteresis margin (HM_{Basic})	3.5 dB
hysteresis margin deviation (ΔH)	1.5 and 3.5 dB
threshold (Th)	0 dB
time-to-trigger (ΔT)	300 ms
measurement report period	100 ms
generation rate of E-MBMS and non-E-MBMS users	0.034

only 1 ms and a radio frame consists of 10 subframes. Traffic data of E-MBMS users in MBSFN area are transmitted using an MTCH, while MCCH carries control information are associated with all MTCHs transmitted in the MBSFN area. Both MTCH and MCCH in the MAC layer are mapped into PMCH in the physical layer [25]. In this paper, it is assumed that the number of subframes for the E-MBMS services in the MBSFN area is 2 and the remaining subframes are assigned to unicast services. Since it is assumed that E-MBMS user in MBSFN area and E-MBMS user in non-MBSFN area allocate different non-overlapping subframes in adjacent cells, the inter-cell interference between them is not existing. Meanwhile, the E-MBMS user in the MBSFN area achieves the macro diversity gain because all the eNBs in the MBSFN area transmit the same signal at the same time and over the same subframe to the E-MBMS users delivering the same content. For the mobility model of all E-MBMS users, this paper adopts the random direction model (RDM) [26]. In this model, each E-MBMS user is generated according to the Poisson arrival process, and the lifetime of each E-MBMS user is assumed to be a random variable with the exponential distribution and with the average lifetime of 2 min. Each E-MBMS user is assumed to move in its own direction with a velocity uniformly distributed from 0 to 140 km/h. We used the path loss model in [27] and the shadowing model in [28]. The shadowing model, which is an updated model for the moving E-MBMS users, is represented by

$$S(t) = W_a S(t-1) + W_b C + W_c V \quad (8)$$

where W_a, W_b and W_c are the weighting factors that should be calculated accordingly to statistical properties of autocorrelation and cross-correlation, for $S(t–1)$, C and V, respectively. The weight W_a is given by $W_a = e^{-1\times(d/d_{corr}) ln2}$ where d is the migration distance of an E-MBMS user with the speed of 70 km/h for 100 ms, d_{corr} is the decorrelation distance between adjacent eNBs. We used d = 1.944 m (=70 km/h × 100 ms) and d_{corr} was set to 33 m. The weights W_b and W_c are given by $\sqrt{R_L S_d^2 (1 - W_a^2)}$ and $\sqrt{S_d^2 (1 - W_a^2) - W_b^2}$, respectively. Here, the cross-correlation of the shadow fading between links (R_L) and shadowing standard deviation (S_d) were set to 0.7 and 6.5 dB. In (8), C is the common value for the wireless links, and V is the zero-mean standard Gaussian random variable with the variance of 1 [28].

5 Simulation results

The performance comparison on the proposed adaptive handover hysteresis scheme for E-MBMS is presented in terms of spectral efficiency and handover latency. Explaining concretely, the number of E-MBMS users supported in the MBSFN area and the available data rate remained in the total cells can be used for evaluating the spectral efficiency, while the handover rate can be utilised for evaluating the handover latency. All figures below are conducted when the MBSFN area size is increased from 1 to 19 and the generation rate of E-MBMS users is fixed as 0.034.

Fig. 8 shows the performance of MBMSRate according to the MBSFN area size and HM deviation (ΔH) when the fixed hysteresis scheme and the proposed adaptive scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area, where MBMSRate is defined as the percent of NuminMBSFN out of NuminMBSFNplusNon-MBSFN such as

$$\text{MBMSRate} = \frac{\text{NuminMBSFN}}{\text{NuminMBSFNplusNon} - \text{MBSFN}} \times 100 \quad (9)$$

where, NuminMBSFN means the number of E-MBMS users supported in the MBSFN area and NuminMBSFNplusNon-MBSFN implies the number of all E-MBMS users serviced in both the MBSFN area and non-MBSFN area. In this paper, the total cell structure consists of 37 3-tier cells. From Fig. 8, we find that the proposed adaptive handover hysteresis scheme achieves higher MBMSRate than the fixed handover hysteresis scheme. As MBMRate implies how many E-MBMS users are supported in the MBSFN area, Fig. 8 shows that the proposed scheme increases the number of E-MBMS users trying to stay in the MBSFN area and handover from the serving non-MBSFN area to the target MBSFN area. In other words, it means that the more E-MBMS users in the MBSFN area have more opportunities to share the same subframes. Also, we find that the MBMSRate increases as the MBSFN area size and HM deviation (ΔH) in the proposed scheme become large. Through the simulation result, it is clearly shown that the effect of the HM on the handover performance depends on ΔH.

Fig. 9 represents the performance of AvailableDRRate according to the MBSFN area size and HM deviation (ΔH) when the fixed hysteresis scheme and proposed adaptive scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area. AvailableDRRate is defined as follows

$$\text{AvailableDRRate} = \left(1 - \frac{\text{DRinMBSFS}}{\text{DRinMBSFNplusNon} - \text{MBSFN}}\right) \times 100 \quad (10)$$

where, DRinMBSFS and DRinMBSFNplusNon-MBSFN indicate the data rate of all E-MBMS users supported in the MBSFN area and the data rate of all E-MBMS users serviced in MBSFN area and non-MBSFN area, respectively. In this paper, DRinMBSFNplusNon-MBSFN is calculated as 20×37 Mbps by 3-tier 37 cells. Also, it should be noted that E-MBMS users with the same content are calculated as a single data rate because they share the same subframe. From Fig. 9, we find that the proposed adaptive handover hysteresis scheme provides larger AvailableDRRate than the fixed handover hysteresis scheme. In the above result, the increase in AvailableDRRate means that more E-MBMS users get more chances to share the same subframes like Fig. 8. In other words, it implies that the remaining available subframes are increased, so that the proposed scheme has the advantage that the subframes returned by the positive migration of more E-MBMS users from the serving non-MBSFN area to the target MBSFN area can be assigned to other non-E-MBMS users in the non-MBSFN area if there is no E-MBMS user to use the corresponding subframes in the non-MBSFN area. Also, we observe that AvailableDRRate increases as the MBSFN area size and ΔH in the proposed scheme increase. The results of Figs. 6 and 7 imply that the proposed adaptive handover hysteresis scheme is a better spectral efficiency than the fixed handover hysteresis scheme and larger ΔH improves the spectral efficiency performance.

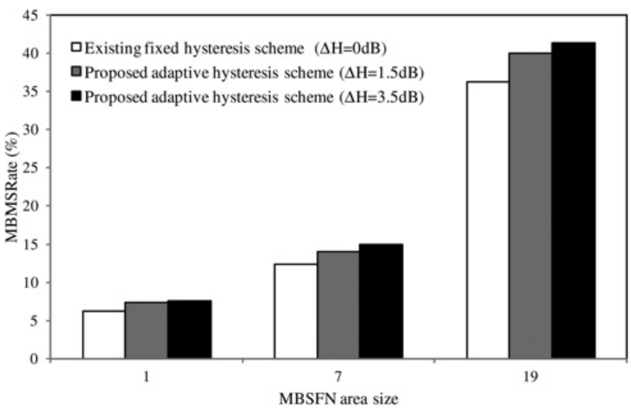

Fig. 8 *Performance of MBMSRate according to the MBSFN area size and hysteresis margin deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area*

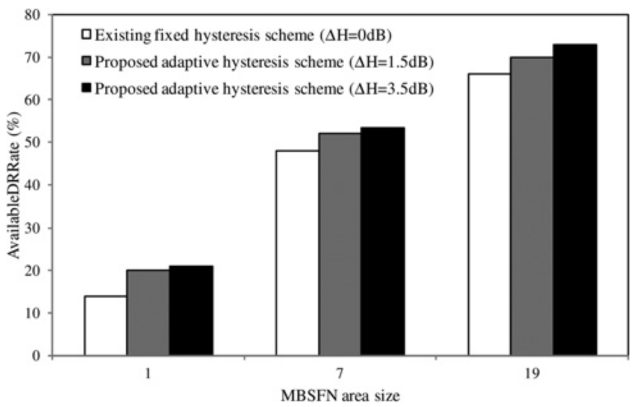

Fig. 9 *Performance of AvailableDRRate according to the MBSFN area size and hysteresis margin deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area*

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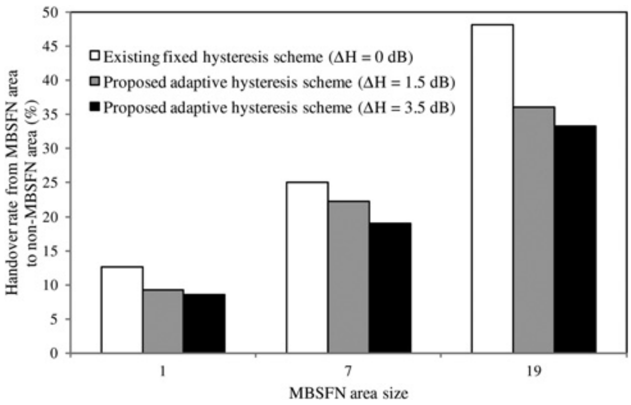

Fig. 10 *Performance of handover rate of the E-MBMS users moving from the serving MBSFN area to the target non-MBSFN area according to the MBSFN area size and hysteresis margin deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area*

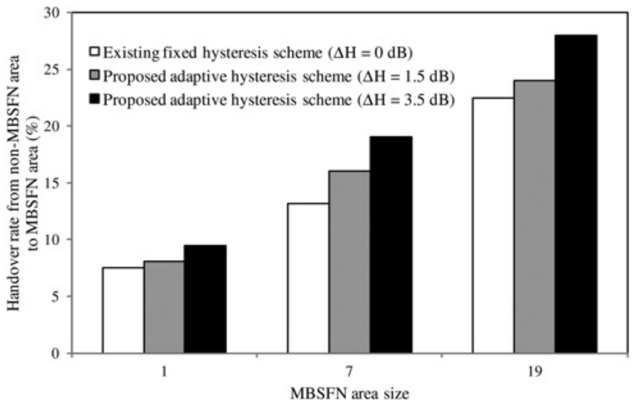

Fig. 11 *Performance of handover rate of the E-MBMS users moving from the serving non-MBSFN area to the target MBSFN area according to the MBSFN area size and hysteresis margin deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area*

Fig. 10 shows the performance of handover rate of the E-MBMS users moving from the serving MBSFN area to the target non-MBSFN area according to the MBSFN area size and HM deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area. Here, the handover rate from the serving MBSFN area to the target non-MBSFN area is defined as the ratio of the number of the handover attempts from the serving MBSFN area to the target non-MBSFN area to the total number summing both the number of the E-MBMS handovers generated inside the same MBSFN area and the number of the E-MBMS handovers between the MBSFN area and the non-MBSFN area. As illustrated in Fig. 3, handover from the serving MBSFN area to the target non-MBSFN area brings about the long handover latency by the additional handover signalling message exchanges to register to MME and BM-SC, while the handover inside the same MBSFN area causes the short handover latency by the handover signalling message exchanges between E-MBMS user and eNB without registering to MME and BM-SC. As shown in Fig. 10, because the handover rate of the proposed adaptive handover hysteresis scheme is less than that of the fixed handover hysteresis scheme, we observe that the proposed adaptive handover hysteresis scheme provides less handover latency than the fixed handover hysteresis scheme. Also, it is found that the proposed scheme with larger ΔH achieves much less handover latency than the proposed scheme with smaller ΔH. Finally, we reach a conclusion that the proposed scheme with larger ΔH plays an important role in the decrease of the handover latency.

Fig. 11 represents the performance of handover rate of the E-MBMS users moving from the serving MBSFN area to the target non-MBSFN area according to the MBSFN area size and HM deviation (ΔH) when the fixed handover hysteresis scheme and proposed adaptive handover hysteresis scheme are applied to E-MBMS handover between the MBSFN area and the non-MBSFN area. In Fig. 11, the proposed adaptive handover hysteresis scheme is larger than that of the fixed handover hysteresis scheme in terms of the handover rate from the serving non-MBSFN area to the target MBSFN area, but the proposed scheme does not increase the handover latency. The reason is because any additional handover signalling messages towards the eNB via MME and BM-SC are not needed if E-MBMS user with the same content already existed inside the same MBSFN area as shown in Fig. 3. Therefore, the handover latency between the fixed handover hysteresis scheme and the proposed adaptive handover hysteresis scheme is the same if E-MBMS user delivering the same content was already generated once more.

After all, as the proposed scheme leads to a lower handover latency in case of the E-MBMS handover moving from the serving MBSFN area to the target non-MBSFN area as shown in Fig. 10 and produces a similar handover latency in case of the E-MBMS handover moving from the serving non-MBSFN area to the target MBSFN area as shown in Fig. 11 compared to the fixed handover hysteresis scheme, it is identified that the proposed scheme provides more handover latency performance. From all simulation results, we conclude that the spectral efficiency and handover latency performances of the proposed adaptive handover hysteresis scheme are better than those of the fixed handover hysteresis scheme.

6 Conclusion

This paper presented an adaptive handover hysteresis scheme in the MBSFN area with multiple eNBs for E-MBMS services. The proposed scheme encourages more E-MBMS users to stay within the MBSFN area by controlling dynamically the handover HM according to the handover direction. As a result, as the number of E-MBMS users that are supported within the MBSFN area increases and the additional handover signalling message exchanges towards the eNB via MME and BM-SC for E-MBMS Registration/Deregistration and Session Start/Stop procedures decrease, the performance of the proposed scheme can be improved in terms of spectral efficiency and handover latency. Through the simulation results, as it is verified that the proposed adaptive handover hysteresis scheme provides better spectral efficiency and less handover latency than the fixed handover hysteresis scheme, the proposed scheme would provide valuable information to design a hard handover HM for E-MBMS system where the MBSFN area and the non-MBSFN area coexist.

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