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Single Frequency Network Evaluations For Multimedia Broadcast and Multicast Service (MBMS) Implementation In Outdoor and Indoor Area

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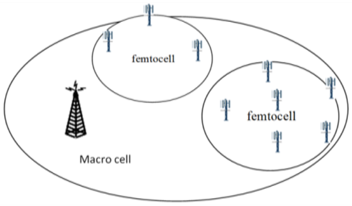
Graphical abstract



Abstract

This paper presents the investigation of Multimedia Broadcast and Multicast Service (MBMS) implementation and its development in Long Term Evolution (LTE) technology. Where, it is using all the LTE advantages such as high data rates for Uplink and Downlink, and mobile support. The implementation of MBMS in LTE has improved all the problems occurred in the previous technology and introduce new alternative in broadcasting technology as well. In addition to that, the transmission mode known as Single Frequency Network (SFN) is used to improve the performance of the MBMS signal received by users in indoor and outdoor area. The evaluation on outdoor area concerns from the Base Station (BS) to the cell edge area. The investigation of data rate for certain number of user equipment is carried out at five different frequencies using SEAMCAT simulator. Then, the Signal Interference to Noise Ratio (SINR) is evaluated for three different users, which located at three different locations using MATLAB.

Keywords: Femtocell; multimedia broadcast and multicast service; single frequency network

Abstrak

Kertas ini membentangkan penyiasatan untuk pelaksanaan Perkhidmatan Penyiaran Mudah Alih dan Berbilang Tugas (MBMS) dan pembangunan sistem ini dalam teknologi Evolusi Jangka Panjang (LTE). Di mana, ianya menggunakan semua kelebihan LTE seperti kadar data tinggi untuk pindah naik dan pindah turun dan sokongan mudah alih. Perlaksanaan MBMS di dalam LTE telah memperbaiki semua masalah yang berlaku dalam teknologi terdahulu dan memperkenalkan alternatif teknologi penyiaran baru. Di samping itu, mod penghantaran yang dikenali sebagai rangkaian frekuensi tunggal (SFN) digunakan untuk meningkatkan prestasi isyarat MBMS yang diterima oleh pengguna di kawasan dalaman dan luaran. Penilaian pada kawasan luar meliputi dari stesen pangkalan (BS) ke kawasan pinggir sel. Penyiasatan dijalankan terhadap kadar data untuk bilangan pengguna tertentu bagi lima jenis frekuensi yang berbeza menggunakan simulator SEAMCAT. Kemuadian, Nisbah Isyarat kepada Hingar (SINR) bagi tiga pengguna yang berbeza dinilai, di tiga lokasi yang berbeza menggunakan MATLAB.

Kata kunci: Femtocell; perkhidmatan penyiaran multimedia dan berbilang tugas; rangkaian frekuensi tunggal;

■1.0 INTRODUCTION

The rapid growth in communication technology such as wireless mobile recently has brought many improvements to satisfy the user demand, which involve the evolution from the previous technology. This evolution has brought many attractive services in mobile communication where it leads to the introduction of smartphones and tablets. Hence, users have access to services such as news, multimedia contents and social web through their handheld devices. These multimedia services in wireless communication technology require high data rate transmission from base station to users. This requires high performance of the wireless communication system and it could be affected by many factors including coverage of the signals, bandwidth and also frequency band allocation [1].

Most of the use of the handheld devices is in indoor area such as homes, shopping malls and offices, where the signal loss is the major problem. The degradation of the signals is affecting the signal coverage and data throughput performance. According to a research by Zhao, *et. al* in [2], it is predicted that in future, more than 70% of data rate traffic generated from mobile phones in indoor area. Thus data rate becomes worst when a lot of users use their device simultaneously [3]. Therefore, there is a need of research and development to overcome this problem. One of the solutions is the improvement and evolution in the wireless mobile technology itself. For example, the evolutions and enhancements in mobile technology begin with the 2nd Generation (2G) that has GSM, GPRS and EDGE. Then, it evolved to 3rd Generation (3G), which consist of UMTS, HSDPA, HSUPA and HSPA+ and LTE. LTE itself later evolved to LTE-Advanced (LTE-A) or also known as 4th Generation (4G) that can offer higher data rate for Uplink (UL) and Downlink (DL) [4] and fulfill the International Mobile Telecommunication (IMT) specifications.

LTE introduced MBMS in Release 8, where it is can be used to deliver multimedia contents and support Single Frequency Network (SFN). The SFN is one of the alternatives to improve the signal degradation from the Base Station (BS) especially in the cell edge in outdoor area, which caused by factors like the geographical location, penetration loss in indoor area and interference from adjacent cell. Commonly, users at cell edge will suffer from the degradation of signal due to propagation loss. This is contributed from the situation of long distance between user equipment and BS, and signal interference at adjacent cell. Therefore, SFN is chosen to improve the data rate transfer all over the cell with existence of constructive interference compared to unicast used in UMTS technology. Even though, unicast signal is efficient in spectrum usage but it produces destructive interference at cell edge. The MBMS technology is then will be discussed further in Section 2.

■2.0 ,MULTIMEDIA BROADCAST AND MULTICAST SERVICE (MBMS)

MBMS is a new alternative in broadcasting technology, which specifically introduced for handheld devices that evolved from service concept in 3rd Generation Partnership Project (3GPP) that can deliver broadcast and multicast service. Many advantages offered by this new broadcasting technology as it is designed by 3GPP to fulfill the requirements of multimedia applications for mobile user and provide broadcast and multicast service with the use of existing mobile infrastructures [5]. Furthermore, MBMS is capable to deliver multimedia contents to multiple users at the same time over the existing radio frequency resource without the requirement of any additional spectrum.

Actually, it has been introduced earlier in UMTS-3G Release 6 and then re-introduced in LTE Release 8 with several improvements from previous release. In UMTS Release 6, MBMS is offered by using the point-to-point (PtP) connections [5]. Point-to-point (PtP) is the transmission link that dedicated for only one user. It is only efficient when there is one user request at a time. After many enhancements, the MBMS is then re-introduced in Release 8 LTE with the use of Orthogonal Frequency Division Multiplexing (OFDM) in the physical layer. This is due to OFDM capable in producing high data rates, large transmission bandwidth and flexible in frequency allocation [6]. It is also meeting the IMT requirements for mobile evolution.

In Release 8, the MBMS has two options to deliver its signal, which are single-cell and multi-cell. While, the transmission of the MBMS signal can be divided into three types of modes. There are point-to-point (PtP), point-to-multipoint (PtM) and Single Frequency Network (SFN). For PtM mode, it allows the user to share same information in same radio resource, regardless the number of user inside. Then, for the case PtP mode, the transmission link is assigned for one user, which led to inefficient spectrum usage. As PtM is widely used in broadcasting, it is used to produce Single Frequency Network (SFN). SFN allows all base stations to transmit same signal at the same time over the same frequency channel to the user equipment (UEs) with the consideration of time synchronization [1,7]. Where, the combination of signals from different eNB will produce constructive interference. Therefore, this advantage is taken into MBMS in multi-cell that can be known as MBMS over Single Frequency Network (MBSFN) [8].

In MBSFN, Orthogonal Frequency Division Multiplexing (OFDM) is also chosen to be implemented due to its capability to produce higher spectral efficiency together with wider bandwidth [9]. Furthermore, the OFDM signal is able to support SFN due to the existing of cyclic prefix time (CP). The cyclic prefix time allows the multipath signal to be combined together to produce constructive signal when the transmitted signals arrived within the CP time. Consequently, CP in OFDM is capable to reduce the Intersymbol (ISI) and Intercarrier interference (ICI) [10].

In MBMS, another important feature affecting its performance is frequency selection. Even though, MBMS in LTE technology operates at 1.8 and 2.6 GHz [11], there is a possibility to operate at lower spectrum in digital dividend band. Where, the investigation of this possible frequency selection will be discussed in the following Section 3.

■3.0 IMPLEMENTATION OF MBMS IN DIGITAL DIVIDEND BAND

MBMS is a technology that uses the existing LTE infrastructure; hence there is no specific frequency that has been allocated to this service yet. Frequency of 1.8 and 2.6 GHz are widely used as the carrier frequency for LTE including Malaysia [11]. Meanwhile, currently the lower frequency such as in VHF and UHF band cannot be used by MBMS as these bands are allocated for analog broadcasting. There will be free spectrum spaces called digital dividend, which available when the transition from analog to digital broadcasting is fully completed.

The European Union (EU) has agreed in Geneva Agreement 2006 (GE06) that the switching to the digital broadcasting is started in early 2012 [12]. The digital dividend band frequency is expected to be located in VHF and UHF band from 174 to 230 MHz and 470 to 862 MHz, accordingly. The free spectrum may vary among the countries resulting from the geographical position and penetration of other services such as satellite or cable service [13]. This spectrum is very precious because it can give wider coverage and advantage, even though the number of UE is increased. Therefore, this digital dividend can be utilized in MBMS implementation for indoor and outdoor area. In this article, SFN is chosen as transmission mode of MBMS. Therefore, the simulation parameters to evaluate SFN for MBMS technology are listed in Table 1.

The simulation parameters in Table 1 are adapted from Wibowo *et al.* [14] and Femto forum report [15] to create the actual LTE transmission with additional parameters, which are number of UE and frequency variation. There are in total 7 hexagonal cells (1-tier of cells) to represent the SFN scenario with each of the BS transmits 46 dBm power. The evaluation is focusing on the average data rate achieved by UE in SFN area, where the number of UE is varied from 3 to 100 UEs. The carrier frequency is varied from 700 MHz to 2.6GHz. These carrier frequencies are selected based on the LTE technology except for the 700 and 800 MHz. 700 and 800 MHz are referring as potential available frequency from digital dividend. The simulation is using propagation model of ITU-R P.1546 as it has been used in Digital Video Broadcasting for Terrestrial (DVB-T).

Referring to Figure 2, through a simulation applying the parameters in Table 1, the data rates can be noted to be just slightly decreased with the increasing of UE due to the data traffic congestions between all UEs. The highest data rate is achieved by using the lowest carrier frequency, which is 700 MHz and followed by 800, 900, 1800 and 2600 MHz. It can be seen that the decrement in average data rate is low as the average received data is almost static. Therefore, it shows that the data loss not much affected even though the number of UE is increased. Based on the simulation result, 700 MHz carrier frequency which is located in digital dividend band gives the best performance and has very good potential to be implemented for the MBMS service. This evaluation is performed using SEAMCAT simulator, which present the average data rate for outdoor area. The evaluation for indoor area involves the MBSFN in femtocell will be explored in the next Section 4 and 5.

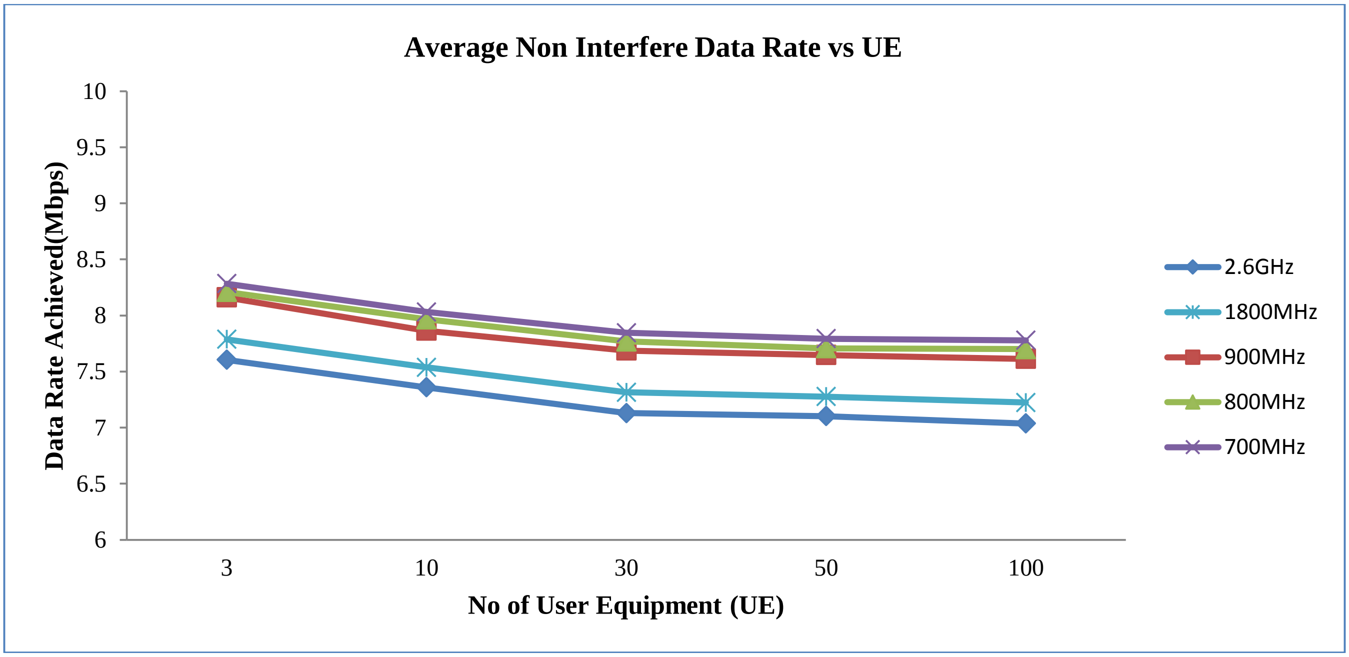


Figure 1 Data rate versus the number of user equipment (UE)

Table 1 Simulation parameters of single frequency network for MBMS technology

Parameter	Value
Cellular Layout	Hexagonal
Cell Radius	0.433 km
No of cell	7 cells
Transmit Power	46 dBm
Bandwidth	5 MHz
Carrier Frequency	2.6 GHz, 1800 MHz, 900 MHz, 800 MHz and 700 MHz.
Number of UE per cell	3 to 100
Cell Layout	1–tier Omnidirectional
User Mobility	1.44 km/h
Propagation Model	ITU-R P.1546

■4.0 MBMS OVER SINGLE FREQUENCY NETWORK (MBSFN) IN FEMTOCELL

The signal from base station in macrocell may degrade due to the propagation and penetration loss [1] before it received by the indoor UE. The geographical conditions like terrains and carrier frequency selection contribute to the propagation loss. Meanwhile, according to 3GPP TR 36.814 [16], the value penetration loss from outdoor to indoor is 20 dB and this value is quite high. Therefore, femtocell has been introduced in cellular technology to improve the signal reception near the cell edge and specifically used in indoor area because of the wall penetration loss. In addition, the implementation of femtocell will reduce the traffic congestion in macro base station. This will ensure every user in the macrocell able to access and use the service. Furthermore, it has proven to be very power efficient due to the use of low power at HeNB [17]. Hence, particularly in MBMS, the introduction of femtocell by 3GPP offers an advanced and effective solution to the signal loss to users in outdoor and indoor area at cell edge area.

The implementation of Single Frequency Network (SFN) is not limited to the macro cell area. The use of femtocell that introduced in LTE improves the data rate and signal coverage in indoor area because of the signal from the base station in macro cells has limitations to the thick walls and other indoor obstacles [14]. As SFN in macro-cell, it acts as the same way in femtocell area where all the base station are known as Home eNB (HeNB) will transmit the same signal over the same time and frequency channel to the UE with the time synchronization [18]. The used of OFDM with CP, which has been discussed in Section 2, is able to prevent the interference between multiple signals and produce constructive interference. This only valid to the broadcast and multicast case, but not to unicast.

Figure 2 shows the critical area around the cell edge. Where, the users in that area will face the stated problems and femtocell is used as a solution. Even though to cover a very large coverage area, the BS is not allowed to transmit higher power signal than the standard. This is due to the signal may high at certain area in macro-cell but an interference might occurred to other adjacent cell near the cell edge. Therefore, users at the cell edge where the signals from adjacent cell may overlap will suffer the signal degradation. So, the used of femtocell will overcome this problem. Hence, to create SFN, the MBMS is implemented in femtocell using multi-cell.

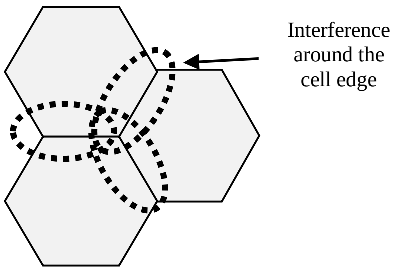


Figure 2 The interference at cell edge

The implementation of multi cell in femtocell area can be illustrated as in Figure 3. Where, inside the macro cell area, there are many femtocell areas. These femtocells are randomly located and equipped with home base station known as HeNB. More than 1 HeNB is needed to create multi cell area and then, SFN can be created. Normally, HeNB transmits a low power signal compared to high power signal transmitted by eNB in macro cell.

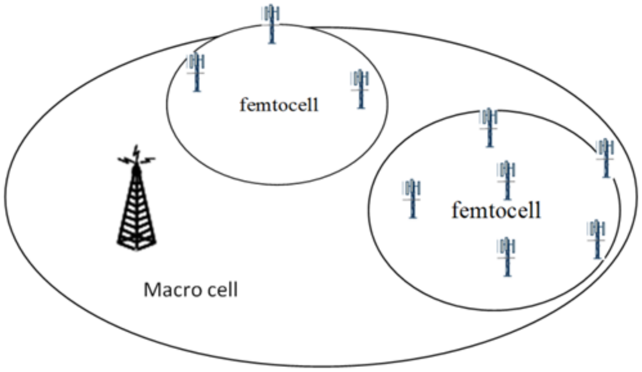


Figure 3 Implementation of femtocell at cell edge area

Where, n and m are number of interfering cell and signal path from adjacent HeNB to receiver, respectively. While, w is the used weight function calculated from equation (4). Then, τ_i, δ_i, P_j, q_i are propagation time delay, additional time delay, power associate with path *j* and propagation path loss, accordingly.

Figure 4 is adapted and modified from O.Bataa *et al.* [17] to show the architecture of MBMS with the support of Home eNB (HeNB). The multimedia contents from the content providers are connected to the eMBMS server and then, to the Gateway before transmitted to the macro cell base stations (eNB). The multimedia contents also distributed to other small base stations (HeNB) that basically located in the small building and houses. All the base stations have mobility management support that controlled by Mobility Management Entity (MME) in order to control session signaling.

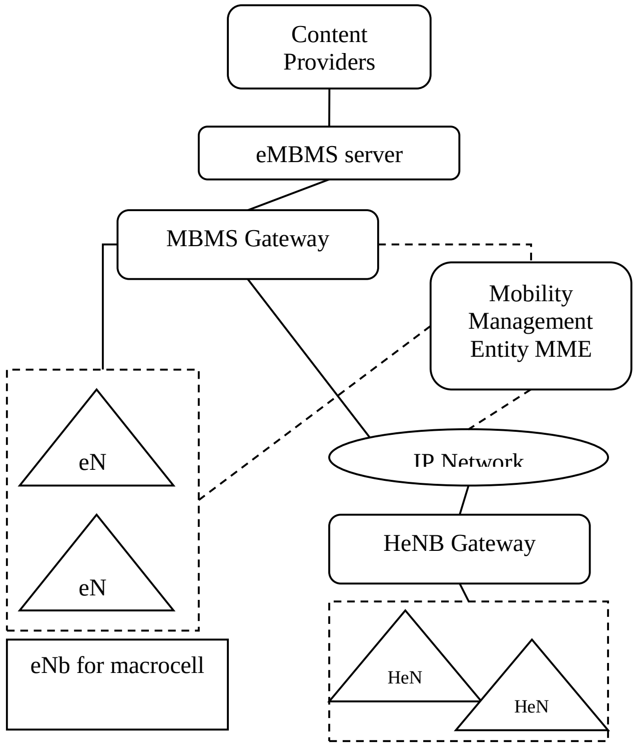


Figure 4 MBMS E-UTRAN architecture with HeNB

■5.0 EVALUATION OF SINGLE FREQUENCY NETWORK FOR MBMS IN FEMTOCELL

The performance of UE in femtocell is evaluated based on Signal Interference to Noise Ratio (SINR). UE that has higher value of SINR is receiving a good broadcast signal. To evaluate and determine the SINR for each UE, following equation (1) can be used [18]:

$$SINR_{SFN}(m) = \frac{\sum_{i=0}^{n}\sum_{j=1}^{M}\frac{w(\tau_i+\delta_j)P_j}{q_i}}{\sum_{i=1}^{n}\sum_{j=1}^{M}\frac{\left(1-w(\tau_i+\delta_j)\right)P_j}{q_i}+N_0} \qquad (1)$$

Where, n and m are number of interfering cell and signal path from adjacent HeNB to receiver, respectively. While, w is the used weight function calculated from equation (4). Then, τ_i, δ_i, P_j, q_i are propagation time delay, additional time delay, power associate with path *j* and propagation path loss, accordingly. Whilst, N_0 is a constant of noise spectral density with -174 dBm/Hz.

The required propagation time delay, τ_i in equation (1) can be determined from (2):

$$\tau_i = \frac{r_i - r_o}{c} \tag{2}$$

Where r_i, r_0 and c are the distance between UE to neighbouring HeNB (i = 1, 2, 3…….8), the distance between serving HeNB (base station 0) to the UE and speed of light, accordingly.

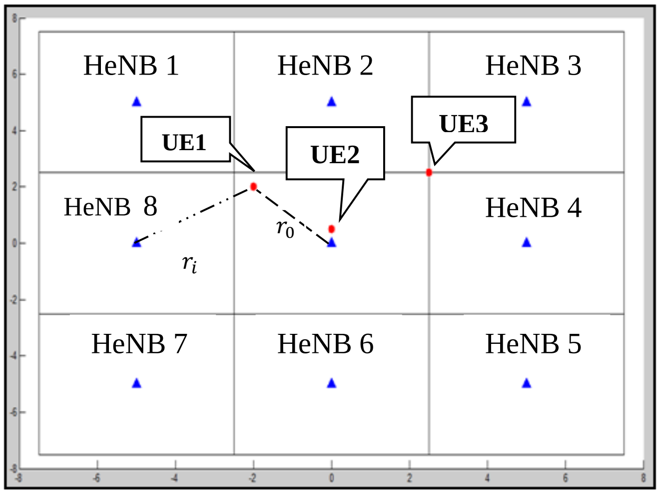
Then, the propagation path loss for indoor area can be computed by referring to Technical Report TR 36.814 [16]. Where, the path loss equation is expressed as equation (3):

$$\text{PL (dB)} = 38.46 + 20\log r_0 + 0.7r_0 \tag{3}$$

Where r_0 is the distance of HeNB to UE in meter. Then, the weight function of constructive portion of the received SFN signal is chosen depending on the equation (4) [18]:

$$w(\tau) = \begin{cases} 1, & 0 \le \tau < T_{CP} \\ \left(1 - \dfrac{\tau - T_{CP}}{T_u}\right)^2, & T_{CP} \le \tau < T_{CP} + T_u \\ 0, & Otherwise \end{cases} \tag{4}$$

where, T_{CP} and T_u are the cyclic prefix time and useful signal frame length, respectively. The weight function is needed to be computed for each of the received multipath signal with the consideration of fast fading delay [18].



▲	HeNB (Base Station in femtocell)
●	User (UE) Location

Figure 5 Location of three User Equipment (UE) in femtocell area

Figure 5 shows the femtocell area that is used to evaluate the SINR for three UEs by using MATLAB. The evaluation is based on the area of 15 x 15 meter area. These three UEs are randomly placed and the distance of each UE is calculated by taking the center HeNB as reference cell, which surrounded with 8 adjacent HeNB.

Table 2 and 3 show the distance from reference cell 0 to the UE location and propagation time delay (τ), accordingly. The calculated distances are then used to calculate the propagation time delay. Later, the propagation time delay is used to determine the weight function. The weight function selection is based on the equation (4), which depend on the T_{CP} and T_u. The used value of T_{CP} and T_u are 16.67 and 66.67 µs, respectively to meet the requirement for SFN cyclic prefix time and avoid the ISI [14].

Table 2 Distance between adjacent eNB to three different user equipment (UE)

UE Point / Symbol	Distance to UE (meter)		
	Point 1 (UE1)	**Point 2 (UE1)**	**Point 3 (UE1)**
$r_0(reference)$	2.828	0.707	3.536
r_1	4.243	7.106	7.906
r_2	3.606	4.528	3.536
r_3	7.280	6.364	3.536
r_4	7.280	4.528	3.536
r_5	9.899	7.106	7.906
r_6	7.280	5.523	7.906
r_7	7.616	7.778	7.778
r_8	3.606	5.523	5.523

Table 3 Propagation time delay for 3 UEs

Propagation time delay (sec)	**(UE1)**	**(UE2)**	**(UE3)**
τ_1	4.716E-09	2.133E-08	1.457E-08
τ_2	2.593E-09	1.274E-08	0
τ_3	1.484E-08	1.886E-08	0
τ_4	1.484E-08	1.273E-08	0
τ_5	2.357E-08	2.133E-08	1.457E-08
τ_6	1.484E-08	1.605E-08	1.457E-08
τ_7	2.539E-08	2.357E-08	1.414E-08
τ_8	2.593E-09	1.605E-08	1.414E-08

The distance from adjacent HeNB to the UE location by taking HeNB 0 as reference cell can be noted from Table 2. After that, the equation (2) is used and the values for the propagation time delay for three UEs are listed in Table 3. These values are then used to select the propagation weight function by referring to the condition as stated in equation (4). Then, the calculated values of propagation path loss, q_i for the three UEs are listed in Table 4. These values are computed from equation (3) depending on the UE distance to the all HeNB.

The SINR of the three users are then calculated with the use of obtained parameters in Table (2) to (4) using equation (1). The SINR values for the three different UE are listed in Table 5. The SINR value for UE1 is about 27.85 dB while UE2 is 37.52 dB. The distance for both UE from the serving base station is different, where UE 2 is nearer to reference HeNB compared to UE1. The SINR for UE2 is higher than UE 1 with the effect of distance and the path loss from adjacent HeNB. However, the most critical area for cellular network is at the cell edge. The SINR value for UE3 that located at edge of the cell is about 27.74 dB. Thus, it is shown that the signal from adjacent HeNB not causing destructive interference but resulting better SINR than UE1.

Table 4 Propagation Path loss q_i

	Propagation path loss (q_i) (dB)		
q_i	**UE1**	**UE2**	**UE3**
q_1	53.98	60.47	61.95
q_2	52.12	54.75	51.91
q_3	60.80	58.99	51.91
q_4	60.80	54.75	51.91
q_5	65.30	60.47	61.95
q_6	60.80	57.17	61.95
q_7	61.43	61.72	61.72
q_8	52.12	57.17	57.17

Table 5 SINR values for 3 different UE locations

Location of UE from reference cell	**Distance to Serving Base Station (m)**	**SINR (dB)**
Point 1 (UE1)	2.828	27.85
Point 2 (UE2)	0.500	37.52
Point 3 (UE3)	3.536	27.74

■6.0 CONCLUSION

In this article, a new broadcast technology of MBMS has been presented for indoor and outdoor area. Through the investigation, it has been proven that at the SFN has improved the coverage around the cell edge with producing constructive interference instead of destructive interference. The improvement has been observed through SINR for three UEs. Even though the UE is at the cell edge with longest distance from serving base station, a good SINR performance still can be achieved. For the frequency selection, the digital dividend frequency has been noted to have higher data rate compared to other frequency spectrum. While, the indoor coverage then has been enhanced with the use of femtocell. Therefore, MBMS over Single Frequency Network (MBSFN) implementation with femtocell for indoor has shown agreeable performance even at the cell edge.

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