IEICE TRANS. COMMUN., VOL.E97–B, NO.1 JANUARY 2014

PAPER

Analysis of the Network Gains of SISO and MISO Single Frequency Network Broadcast Systems*

Sungho JEON[†,††a)], ***Member***, **Jong-Seob BAEK**[††,†††b)], **Junghyun KIM**[†c)], ***Nonmembers***, ***and*** **Jong-Soo SEO**[††d)], ***Member***

SUMMARY The second generation digital terrestrial broadcasting system (DVB-T2) is the first broadcasting system employing MISO (Multiple-Input Single-Output) algorithms. The potential MISO gain of this system has been roughly predicted through simulations and field tests. Of course, the potential MISO SFN gain (MISO-SFNG) differs according to the simulation conditions, test methods, and measurement environments. In this paper, network gains of SISO-SFN and MISO-SFN are theoretically derived. Such network gains are also analyzed with respect to the receive power imbalance and coverage distances of SISO and MISO SFN. From the analysis, it is proven that MISO-SFNG is always larger than SISO SFN gain (SISO-SFNG) in terms of the achievable SNR. Further, both MISO-SFNG and SISO-SFNG depend on the power imbalance, but the network gains are constant regardless of the modulation order. Once the field strength of the complete SFN is obtained by coverage planning tools or field measurements, the SFN service coverage can be precisely calibrated by applying the closed-form SFNG formula.

key words: *power imbalance, single frequency network (SFN), DVB-T2 MISO processing, calibrated coverage prediction*

1. Introduction

Planning of transmission networks for analog broadcasting systems like FM broadcasting is traditionally based on the concept of multiple frequency networks (MFNs). In MFN, adjacent transmitters radiate the same programme at different frequencies to avoid interference of the signals where the coverage areas of different transmitters overlap. In contrast, orthogonal frequency division multiplexing (OFDM)-based digital broadcasting systems like DVB-T2 [1] can deploy single frequency networks (SFNs) [2], where all transmitters of the network transmit the same programme at the same time on the same frequency. In such SFNs, multiple transmitters with low power cover the total service area so that the signals arriving at the receiver with different delays from the transmitters are superposed. Because this phenomenon yields better coverage and spectral efficiency than in MFNs, this is usually referred as *network gain* [3].

Regarding conventional single-input single-output (SISO) SFNs the first evolution in the history of broadcast networks, multiple-input single-output (MISO) SFNs might be the second evolution. To enhance the coverage and throughput even more, DVB-T2 adopts a distributed MISO technique named *MISO processing* based on Alamouti coding [4], [5]. Because of the commercial requirement of DVB-T2 standardization [1] that the viewer's antenna installation should be left untouched, the use of only one receive antenna is permitted. The MISO processing technique includes the geographical distribution of the transmitters in two separated groups. One group transmits the normal signal and the other group transmits the signal coded by the Alamouti encoding rule. Therefore, in the current broadcast network configuration, MISO SFN is considered the simplest to implement in real deployments.

It has been shown that network gain can be obtained by both the MISO-based SFN and the conventional SISO SFN. In practical deployment of MISO SFN and SISO SFN, MISO SFN gain (MISO-SFNG) and the conventional SISO SFN gain (SISO-SFNG) at the receiver are shown to depend strongly on the receive power imbalance of SFN [6]–[10]. The SISO SFN gain can be obtained by simply adding all the receive field strengths. However, MISO SFN gain cannot be obtained in a simple process [11], and it needs to be predicted by computer simulations [6]–[9], laboratory experiments [10], or field measurements [12]. In [6], it is shown that the MISO SFN gain is positive when the receive power imbalance is under 6∼7 dB, and negative when it is over 7 dB. In [9], MISO SFN gain is shown to be affected by network hierarchy and antenna types such as ommi-directional and sectorized antennas. In addition, the MISO gain increases slightly as the network gets denser. In [7], [8], the bit error rate (BER) performance is discussed as impacted by the number of transmitters involved with different configurations of MISO networks under the erasure channel [13] with 0 dB echo. Some combinations were found to be worse than the conventional SFN case, and thus, it is necessary to optimize the allocation of transmitters for each group for the given SFN channel environment. According to [10], MISO SFN gain would be lower than the conventional SFN gain. In [12], from the field trial in northern Germany, the power

Manuscript received February 7, 2013.
Manuscript revised August 2, 2013.

†The authors are with Technical Research Institute, Korean Broadcasting System (KBS), Seoul, 150-790, Republic of Korea.
††The authors are with the School of Electrical and Electronics Engineering, Yonsei University, Seoul, 120-749, Republic of Korea.
†††The author is with Team of Advanced Technology and System (ATS), Convergence Lab., CTO, LG Electronics, Seoul, 138-804, Republic of Korea.

*This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) [No. 2012R1A2A2A01011372].

a) E-mail: jeonsh@kbs.co.kr
b) E-mail: jongseob.baek@lge.com
c) E-mail: brilliant@kbs.co.kr
d) E-mail: jsseo@yonsei.ac.kr (Corresponding author)

DOI: 10.1587/transcom.E97.B.182

imbalance effect on the MISO SFN gain is verified, and then, the calibrated coverage gain predictor is introduced to compensate the MISO SFN gain under real conditions.

As discussed above, network gain differs according to the simulation conditions, test methods, and measurement environment. Such heuristic approaches have been used to approximate the network gains of SISO and MISO SFNs. In order words, MISO-SFNG and SISO-SFNG have not been theoretically analyzed yet. In this paper, network gains of SISO-SFN and MISO-SFN are derived as a closed-form formula. Such network gains are also analyzed with respect to the receive power imbalance and coverage distances of SISO and MISO SFNs.

2. Analysis on SISO-SFN Gain

2.1 SISO-SFN: Conventional Single Frequency Network

In SFN, all the transmitters transmit the same information at the same time on the same frequency. The critical requirement for the SFN is that all the transmitters need to be synchronized in frequency and fulfill certain time delay requirements [2], [13]. As a result, SFN can be used to extend the service coverage without the allotment of additional frequencies.

The SFN might be based on OFDM signaling, which is very robust against reception of a signal along with its strong echoes. This robustness against multipath reception can be obtained by using a "guard interval." This multipath immunity can be used to build SFN with overlapping network of transmitters. In the overlap areas, the signals within the guard interval are considered as constructive multipath echoes so that the reception quality is improved owing to the multipath reception. This is known as single-input single-output SFN gain (SISO-SFNG). According to [3], the SISO-SFNG is quantitatively defined in terms of modulation error ratio (MER) as follows:

$$\text{SISO-SFNG} = \text{MER}_{\text{SFN}} - \max\left(\text{MER}_n\right) \text{ [dB]}, \tag{1}$$

where MER_{SFN} is the measured MER when all the transmitters involved in SFN are active and MER_n is the measured MER when only one nth transmitter is active.

Since there is no practical way of measuring signal-to-noise power ratio (SNR), MER is preferred over SNR for field measurement. In the analysis, MER is a measure of the SNR in a digitally modulated signal, and hence, MER can be considered analogous to SNR. Consequently, the definition of the SISO-SFNG in (1) can be represented in terms of SNR as follows:

$$\text{SISO-SFNG} = \text{SNR}^{\text{req}}_{\text{SISO}} - \text{SNR}_{\text{s}} \text{ [dB]}, \tag{2}$$

where $\text{SNR}^{\text{req}}_{\text{SISO}}$ is the required SNR of point-to-point SISO transmission and SNR_{s} is the required SNR when SISO-SFN is applied for achieving a certain quality of service (QoS). Thus, in this paper, we may interpret SISO-SFNG as the SNR gap between $\text{SNR}^{\text{req}}_{\text{SISO}}$ and SNR_{s} to achieve a target bit-error probability.

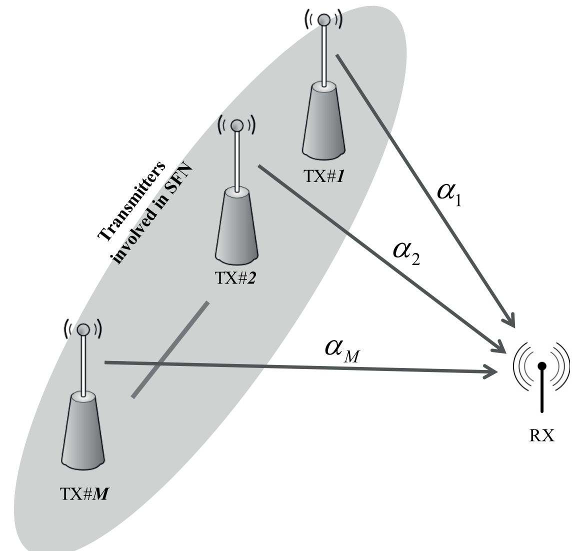


Fig. 1 A general SISO-SFN configuration.

2.2 SISO-SFN Gain as a Function of Receive Power Imbalance

Signal model of each subcarrier in the frequency domain for an SFN is represented as

$$y = \left(\sum_{i=1}^{M} \sqrt{\alpha_i} h_i\right) s + n, \tag{3}$$

where α_i is the relative received power from the ith transmitter with respect to α_1, and $h_i = h_i^I + jh_i^Q$ is the independent unit-variance complex Gaussian distributed channel coefficient between the receiver and the ith transmitter of M transmitter SFN. s is the transmit symbol, n is the additive white Gaussian noise (AWGN) and $j = \sqrt{-1}$.

Here, the effective channel $z_s = \sum_{i=1}^{M} \sqrt{\alpha_i} h_i$ is the sum of complex zero-mean circularly symmetric Gaussian random variables,

$$\begin{aligned} z_s &= \sum_{i=1}^{M} \sqrt{\alpha_i} h_i^I + j \sum_{i=1}^{M} \sqrt{\alpha_i} h_i^Q \\ &= h^I + jh^Q, \end{aligned} \tag{4}$$

where

$$h^I = \sum_{i=1}^{M} \sqrt{\alpha_i} h_i^I \sim \mathcal{N}\left(0, \sigma_h^2 = \frac{1}{2} \sum_{i=1}^{M} \alpha_i X\right), \tag{5}$$

$$h^Q = \sum_{i=1}^{M} \sqrt{\alpha_i} h_i^Q \sim \mathcal{N}\left(0, \sigma_h^2\right), \tag{6}$$

and $\sim$ means "statistically distributed as." Since h_i^I and h_i^Q are independent random variables that are normally distributed, their linear combination will also be normally distributed as (5) and (6).

According to the definition of Chi-square distribution, the variance of the Chi-square random variable should be normalized according to Cochran′s theorem [14], which is used to divide the variance if the Gaussian random variable does not have a unit variance. Therefore,

$$\begin{aligned} |z_s|^2 &= \left|\sum_{i=1}^{M} \sqrt{\alpha_i} h_i\right|^2 \\ &= \left|h^I + jh^Q\right|^2 \\ &= \sigma_h^2 \left(\frac{\left(h^I\right)^2}{\sigma_h^2} + \frac{\left(h^Q\right)^2}{\sigma_h^2} \right) \sim \frac{1}{2} \sum_{i=1}^{M} \alpha_i \chi_2^2, \end{aligned} \tag{7}$$

where χ_k^2 is a Chi-square random variable with k degrees of freedom. Since $(h^I)^2/\sigma_h^2 \sim \chi_1^2$ and $(h^Q)^2/\sigma_h^2 \sim \chi_1^2$, (7) follows the definition of the Chi-squared distribution that the sum of independent chi-squared variables is also Chi-squared distributed, i.e., χ_2^2. Therefore, from the Chernoff upper bound, $Q(x) \leq \frac{1}{2}\exp\left(-x^2/2\right)$ for $x > 0$, the average BER P_e can be obtained as follows [15]:

$$\begin{aligned} P_e &= E\left[bQ\left(\sqrt{a\mathsf{SNR}_{\mathrm{SISO-SFN}}}\right)\right] \\ &\leq \frac{b}{2} E_{\chi_2^2}\left[\exp\left(-\frac{a}{2}|z_s|^2 \mathsf{SNR}_{\mathrm{s}}\right)\right], \end{aligned} \tag{8}$$

where $\mathsf{SNR}_{\mathrm{SISO-SFN}} = |z_s|^2|s|^2/|n|^2 = |z_s|^2\mathsf{SNR}_{\mathrm{s}}$ since $\mathsf{SNR}_{\mathrm{s}} = |s|^2/|n|^2$. $Q(\cdot)$ is the Gaussian Q-function and the parameters (a, b) denote the modulation specific constants. For example, M-ary quadrature amplitude modulation (QAM), $a = 3/(M-1)$ and $b = \frac{q}{\log_2 M}\left(1 - 1/\sqrt{M}\right)$ where q is the compensating factor as a function of modulation order in order to minimize the approximation loss.

From the moment generating function (MGF) of Chi-square random variables

$$M_X(s) = E_X\left[\exp(sX)\right] = (1-2s)^{-1}, \tag{9}$$

the average BER in (8) can be expressed as

$$P_e \leq \frac{b}{2}\left(1 + \frac{a}{2}\sum_{i=1}^{M}\alpha_i \mathsf{SNR}_{\mathrm{s}}\right)^{-1}. \tag{10}$$

After some mathematical manipulations, the achievable SNR for SISO SFN can be obtained as

$$\mathsf{SNR}_{\mathrm{s}} \leq \frac{c}{\sum_{i=1}^{M}\alpha_i}, \tag{11}$$

where $c = 2\left(b/(2P_e) - 1\right)/a$ is a constant. Consequently, SISO-SFNG in (2) can be represented as

$$\mathsf{SISO\text{-}SFNG} = \frac{c}{1+\beta_{\mathrm{s}}}, \tag{12}$$

where $\beta_{\mathrm{s}} = \sum_{i=2}^{M}\alpha_i$ is the receive power imbalance parameter with respect to the reference $\alpha_1 = 1$ for the SISO-SFN case.

3. Analysis on MISO-SFN Gain

3.1 MISO-SFN: MISO Processed DVB-T2

According to Sect. 9.1 "MISO Processing" in [1], DVB-T2 adopts Alamouti-based multiple-input single-output (MISO) networks in the system. This aims to improve the coverage and reception robustness of SISO-SFNs so that the transmitters of two SFN groups form a *distributed* MISO system, providing transmit space and frequency diversities. As shown in Fig. 2, each of the SFN transmitters is assigned to a specific group where each transmitter is regarded as a transmit payload cell in pairs. Therefore, DVB-T2 MISO network can be regarded as an enhanced SFN. The difference between SISO-SFN and MISO-SFN is that the MISO-SFN transmits two different versions of the wanted signal simultaneously from a number of transmitters. Note that Fig. 2 shows a large number of transmitters per group. However, in practice, two or three transmitters are good in a group.

The basic operation of the Alamouti-based MISO network can be understood by referring to Fig. 47 in [1]. Transmitters in *Group 1* transmit an original version of every constellation $\left(a_p, a_{p+1}\right)$ allocated to the subcarriers $(p, p+1)$, just as in SISO-SFN. Transmitters in *Group 2*, however, transmit a modified version of each constellation pair $\left(-a_{p+1}^*, a_p^*\right)$ allocated to the subcarriers $(p, p+1)$ in reverse frequency order, where $*$ denotes the complex conjugate operator.

Similarly to (2), the definition of MISO-SFNG can be represented in terms of SNR as

$$\mathsf{MISO\text{-}SFNG} = \mathsf{SNR}_{\mathrm{SISO}}^{\mathrm{req}} - \mathsf{SNR}_{\mathrm{m}}\ [\mathrm{dB}], \tag{13}$$

where $\mathsf{SNR}_{\mathrm{m}}$ is the required SNR when MISO-SFN is applied for achieving a target bit-error probability.

3.2 MISO-SFN Gain as a Function of Receive Power Imbalance

The signal model for MISO processing, defined in DVB-T2 standards [1], is represented as [5], [18]

$$y = \sqrt{\left|\sum_{i=1}^{T}\sqrt{\alpha_i}h_i\right|^2 + \left|\sum_{i=T+1}^{M}\sqrt{\alpha_i}h_i\right|^2}\, s + n, \tag{14}$$

where the first term of the effective channel can be attributed to *Group 1* and the second term to *Group 2*.

Similarly to (7), the terms $\left|\sum_{i=1}^{T}\sqrt{\alpha_i}h_i\right|^2$ and $|\sum_{i=T+1}^{M}\sqrt{\alpha_i}h_i|^2$ of the effective channel in (14) are also Chi-squared distributed as

$$\left|\sum_{i=1}^{T}\sqrt{\alpha_i}h_i\right|^2 \sim \frac{1}{2}\sum_{i=1}^{T}\alpha_i\chi_2^2 \tag{15}$$

$$\left|\sum_{i=T+1}^{M}\sqrt{\alpha_i}h_i\right|^2 \sim \frac{1}{2}\sum_{i=T+1}^{M}\alpha_i\chi_2^2. \tag{16}$$

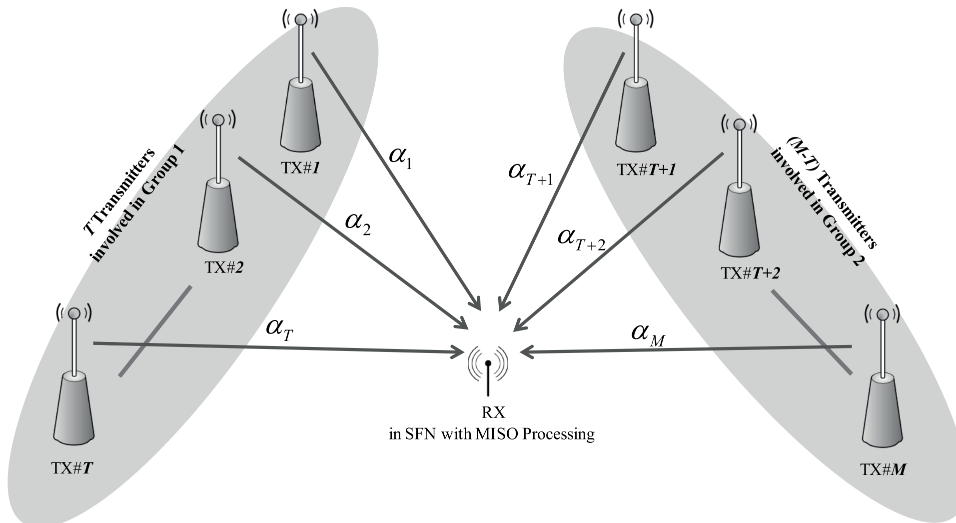


Fig. 2 A general MISO-SFN configuration [11].

$$\mathsf{SNR}_{\mathrm{m}} \leq \frac{-\left(\sum_{i=1}^{T}\alpha_i+\sum_{i=T+1}^{M}\alpha_i\right)+\sqrt{\left(\sum_{i=1}^{T}\alpha_i+\sum_{i=T+1}^{M}\alpha_i\right)^2+2ac\sum_{i=1}^{T}\alpha_i\sum_{i=T+1}^{M}\alpha_i}}{a\sum_{i=1}^{T}\alpha_i\sum_{i=T+1}^{M}\alpha_i} \tag{20}$$

Note that the density function for the distribution of a weighted sum of independent Chi-square random variables cannot be Chi-square distributed [19].

Therefore, the average BER P_e can be obtained by

$$\begin{aligned} P_e &= E\left[bQ\left(\sqrt{a\mathsf{SNR}_{\mathrm{MISO-SFN}}}\right)\right] \\ &\leq \frac{b}{2}E_{\chi_2^2,\chi_2^2}\left[\exp\left(-\frac{a}{2}|z_m|^2\mathsf{SNR}_{\mathrm{m}}\right)\right]. \end{aligned} \tag{17}$$

where $z_m = \sqrt{\left|\sum_{i=1}^{T}\sqrt{\alpha_i}h_i\right|^2+\left|\sum_{i=T+1}^{M}\sqrt{\alpha_i}h_i\right|^2}$ is the effective channel. From the property of MGF, $M_{X+Y}(s) = M_X(s)M_Y(s)$, (17) can be represented as

$$P_e \leq \frac{b}{2}\left(1+\frac{a}{2}\sum_{i=1}^{T}\alpha_i\mathsf{SNR}_{\mathrm{m}}\right)^{-1}\left(1+\frac{a}{2}\sum_{i=T+1}^{M}\alpha_i\mathsf{SNR}_{\mathrm{m}}\right)^{-1}. \tag{18}$$

After some mathematical manipulations, (18) can be arranged as

$$\begin{aligned} &a\sum_{i=1}^{T}\alpha_i\sum_{i=T+1}^{M}\alpha_i\mathsf{SNR}_{\mathrm{m}}^2 \\ &\quad+2\left(\sum_{i=1}^{T}\alpha_i+\sum_{i=T+1}^{M}\alpha_i\right)\mathsf{SNR}_{\mathrm{m}}-2c \leq 0. \end{aligned} \tag{19}$$

From the solution formula for a quadratic equation, the achievable SNR for the MISO-SFN can be obtained by an interval. Due to the Chernoff upper bound condition, $Q(x) \leq \frac{1}{2}\exp\left(-x^2/2\right)$ for $x > 0$, the condition $\mathsf{SNR} > 0$ should be satisfied in (17). As a result, (20) only takes the upper bound of the inequality solution.

Similarly to (1), the definition of the MISO-SFNG can be re-written as:

$$\mathsf{MISO\text{-}SFNG} = \frac{-(1+\beta_{\mathrm{m}})+\sqrt{(1+\beta_{\mathrm{m}})^2+2ac\beta_{\mathrm{m}}}}{2a\beta_{\mathrm{m}}} \tag{21}$$

where $\beta_{\mathrm{m}} = \sum_{i=T+1}^{M}\alpha_i$ is the receive power imbalance parameter with respect to the reference $\sum_{i=1}^{T}\alpha_i = 1 \geq \sum_{i=T+1}^{M}\alpha_i$ for the MISO-SFN case.

4. Simulation Results

4.1 SISO- and MISO-SFNG according to Receive Power Imbalance

For the simulation, each group includes one transmitter so that Alamouti encoding is applied to a couple of transmitters within the SFN. The modulation parameters are chosen to be 4/16/64-QAM. Target BER P_e is set to 10^{-2}.

Figures 3 to 5 show the BER performance of the SISO-SFN, MISO-SFN and SISO systems in Rayleigh fading channel, which illustrate the qualitative effect of the receive power level difference. In order to obtain each sample under the given power imbalance condition, SNR is gradually increased until the BER of $P_e = 10^{-2}$ is reached with a 99.9% confidence level. Achievable SNRs for SISO SFN and MISO SFN as analytically derived in (12) and (21) respectively are shown by lines on Figs. 3 to 5 with respect to the receive power imbalance. The corresponding simulation results are also shown by markers ($\circ, \triangledown, *$) on Figs. 3 to 5, which coincide very well with the analytical results. Both

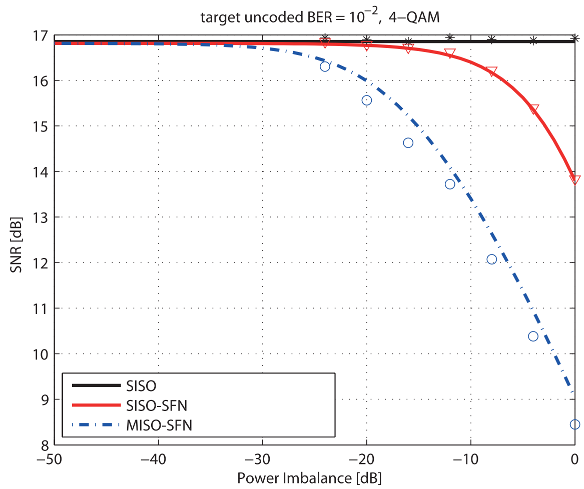


Fig. 3 Impact of receive power imbalance on the performance of DVB-T2 MISO-SFN, SISO-SFN and SISO systems. (4-QAM case, $q = 2.0$)

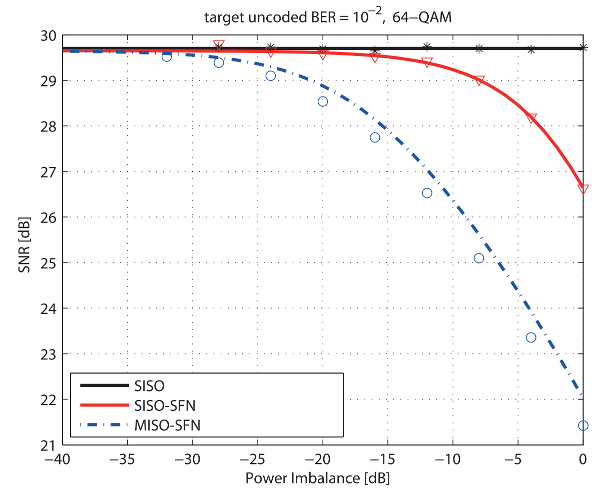


Fig. 5 Impact of receive power imbalance on the performance of DVB-T2 MISO-SFN, SISO-SFN and SISO systems. (64-QAM case, $q = 3.15$)

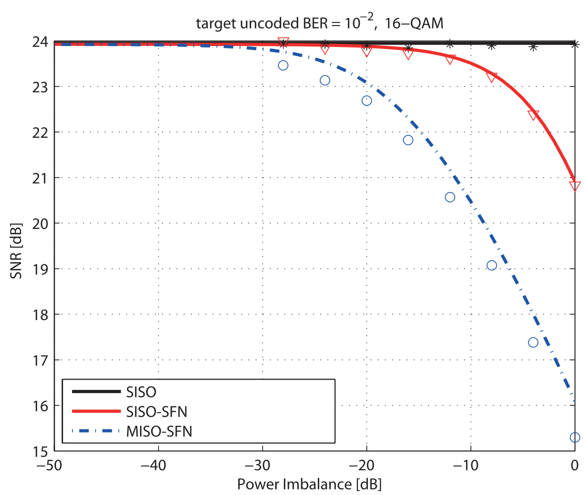


Fig. 4 Impact of receive power imbalance on the performance of DVB-T2 MISO-SFN, SISO-SFN and SISO systems. (16-QAM case, $q = 2.74$)

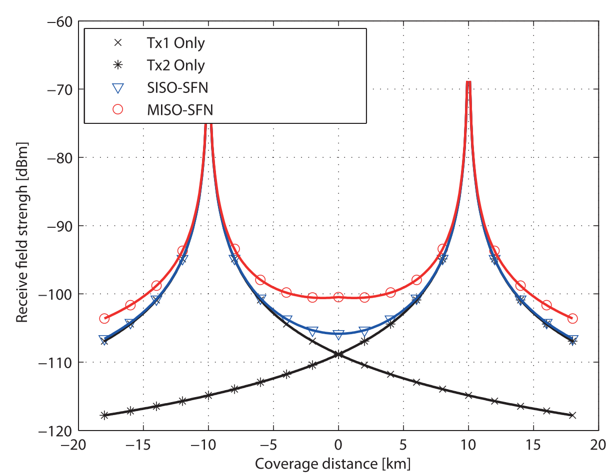


Fig. 6 Receive field strength of SISO-SFN and MISO-SFN compared to SISO transmission.

SISO-SFNG and MISO-SFNG depend on the receive power imbalance and are maximized when signals of equal power from the two different transmitters (groups) are combined. The achievable SNR of MISO-SFN is always lower than that of SISO-SFN. In addition, the SFNGs are constant regardless of modulation order. When the receive power imbalance is 0 dB, for SISO-SFN, exactly 3 dB gain is observed compared to the SISO system. For MISO-SFN, around 5.0 dB additional gain is also observed compared with SISO-SFN. Conversely, the scheme would be of limited benefit in networks with little overlap. As the receive power imbalance decreases, the achievable SNR of both SISO-SFN and MISO-SFN converges to that of SISO.

4.2 SISO- and MISO-SFNG according to Coverage Distance

Receive field strengths and network gains of SISO-SFN, MISO-SFN and SISO transmission can be evaluated for the coverage scenario with two transmitters as shown in Figs. 6 to 10. The transmitters are assumed to be geographically separated by 20 km from each other. The equivalent isotropically radiated power (EIRP) for each transmitter is assumed to be 0 dBm, and the target frequency is 665 MHz (UHF Channel 46 of North America). To calculate the receive power at each point from two transmitters, the simplified Okumura-Hata path loss formula is applied [17]:

$$PL(d) = 20\log_{10} f_c + 20\log_{10} d_n + 32.4, \tag{22}$$

where f_c is a center frequency in MHz, d_n is a distance from nth transmitter in km.

Figure 6 shows the receive field strengths of SISO-SFN and MISO-SFN compared to the SISO transmission. It is shown that the network gain is maximized at the middle of the two transmitters. That is, the receivers located at points with similar signal levels show high SFNG, which may lead to an increase in coverage. If the power imbalance is signif-

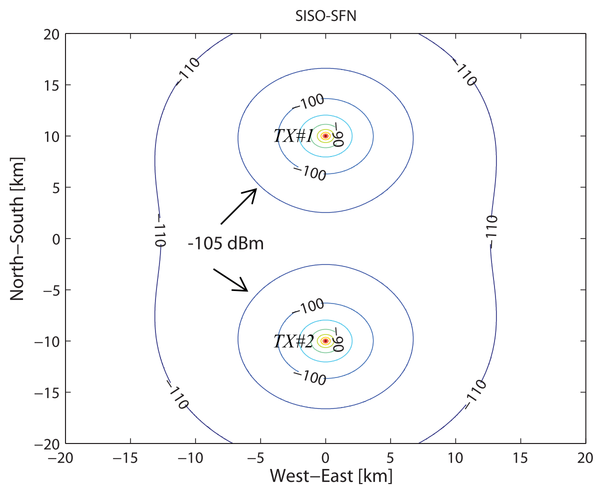


Fig. 7 Receive field strength (dBm) contour of SISO-SFN when $M = 2$.

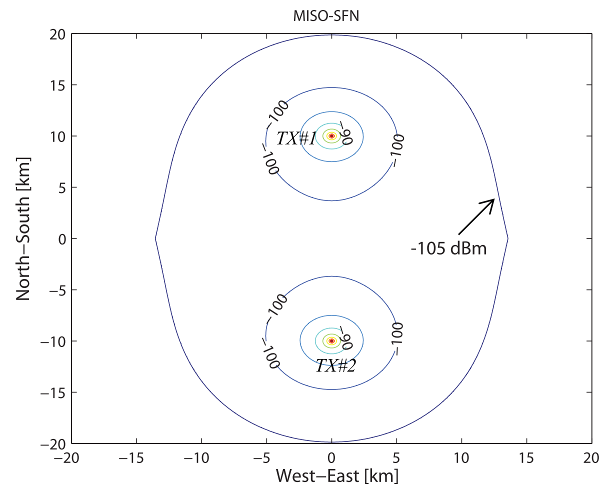


Fig. 9 Receive field strength (dBm) contour of MISO-SFN when $(M, T) = (2, 1)$.

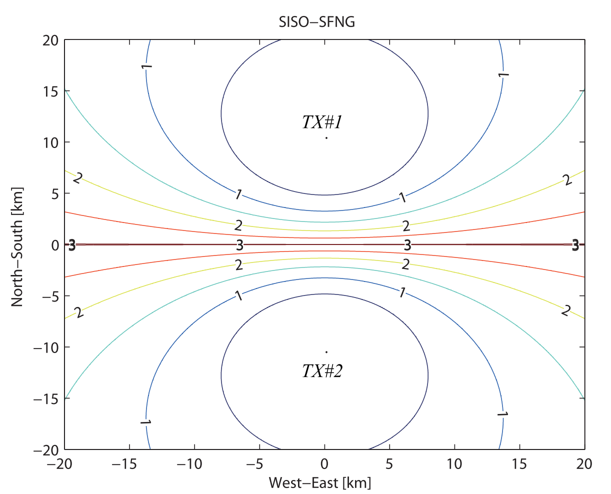


Fig. 8 Achievable SISO-SFNG contour in dB when $M = 2$.

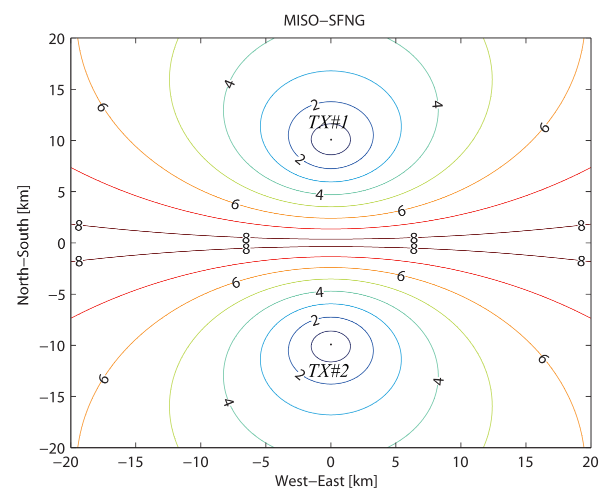


Fig. 10 Achievable MISO-SFNG contour in dB when $(M, T) = (2, 1)$.

icantly high in the areas close to the transmitters, no SISO- and MISO-SFNG can be obtained.

Figures 7 to 10 show the receive power contours and network gains of SISO-SFN and MISO-SFN when transmitter 1 and transmitter 2 are located in (West-East, North-South)= $(0, 10)$ and $(0, -10)$, respectively. The SISO-SFNG and MISO-SFNG are maximized in overlapped areas where the field strengths received from more than one transmitter are comparable. Note that the receive field strength and network gain of MISO-SFN are much larger than those of SISO-SFN, which may lead to an improved SNR as well as extended coverage.

Figures 11 to 14 show the receive power contours and network gains of SISO-SFN and MISO-SFN when the number of transmitters in *Group 1* ($T = 2$) is more than that in *Group 2* ($M - T = 1$). Transmitters 1, 2, and 3 are located in (West-East, North-South)= $(0, 10)$, $(0, -10)$, and $(5, 5)$, respectively. For MISO-SFN, transmitters 1 and 2 are grouped as *Group 1*. Although the SISO-SFNG and MISO-SFNG are still maximized in the overlapped areas, which is the border of each group, the location of the maximum achievable gain is shifted to another point, by comparing Figs. 7 to 10. This is because the receive power imbalance at a certain location is varied as the number of transmitters involved in each group is varied.

Consequently, using (12) and (21), the SISO- and MISO-SFNG for various combinations of network configuration and transmit powers can be quickly obtained without any computer simulation.

5. Conclusion

This paper theoretically analyzed the network gains of SISO-SFN and MISO-SFN broadcast systems. The analysis proved that MISO-SFNG is always larger than SISO-SFNG in terms of the SNR. In addition, both MISO-SFNG and SISO-SFNG are dependent on the receive power imbalance, but the network gain is constant regardless of the modulation order. Once the receive field strength from all the transmitters in SFN is obtained at each point by using

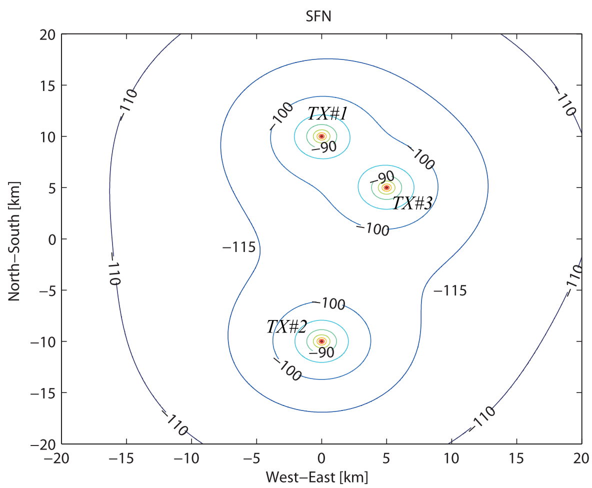


Fig. 11 Receive field strength (dBm) contour of SISO-SFN when $M = 3$.

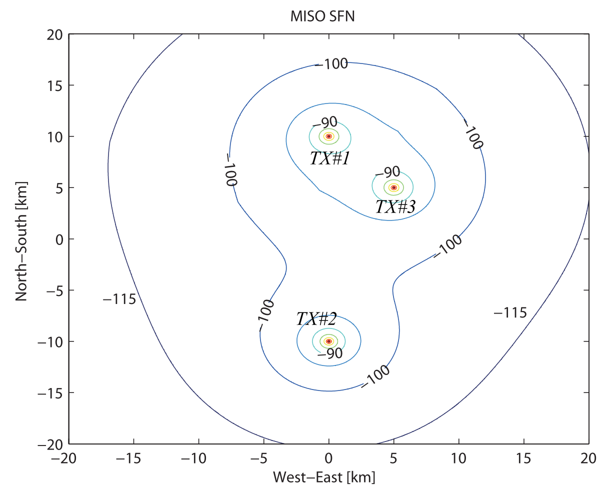


Fig. 13 Receive field strength (dBm) contour of MISO-SFN when $(M, T) = (3, 2)$.

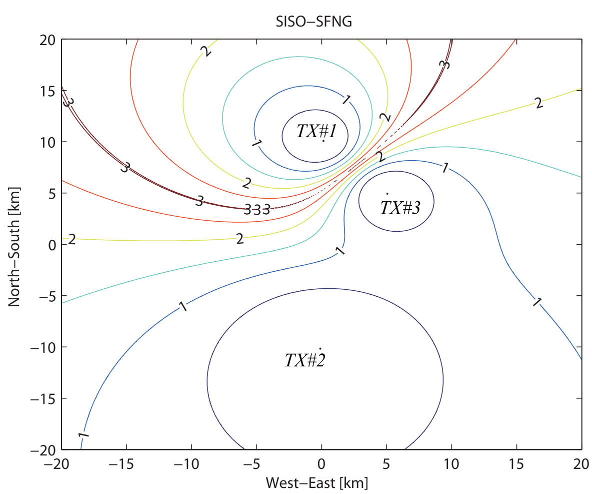


Fig. 12 Achievable SISO-SFNG contour in dB when $M = 3$.

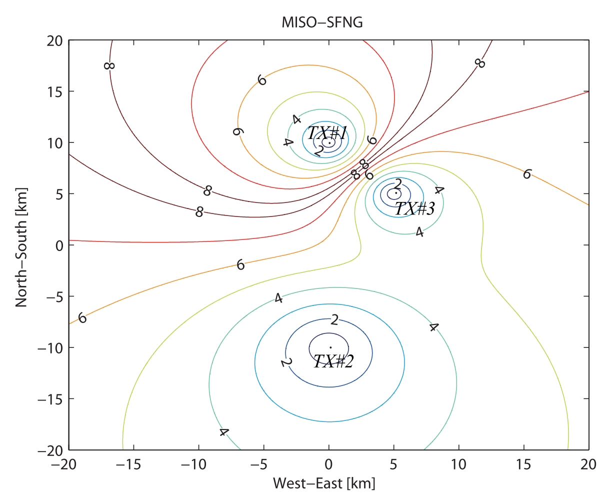


Fig. 14 Achievable MISO-SFNG contour in dB when $(M, T) = (3, 2)$.

coverage planning tools such as CRC-COVLAB [20] or by conducting field measurements, the SFN service coverage can be precisely calibrated by applying the derived closed-form SFNG formula.

References

[1] ETSI EN 302 755, Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2), V1.3.1, April 2012.

[2] A. Mattsson, "Single frequency networks in DTV," IEEE Trans. Broadcast., vol.51, no.4, pp.413–422, Dec. 2005.

[3] D. Plets, W. Joseph, P. Angueira, J.A. Arenas, L. Verloock, and L. Martens, "On the methodology for calculating SFN gain in digital broadcast systems," IEEE Trans. Broadcast., vol.56, no.3, pp.331–339, Sept. 2010.

[4] S.M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE J. Sel. Areas Commun., vol.16, no.8, pp.1451–1458, Oct. 1998.

[5] V. Tarokh, H. Jafarkhani, and A.R. Calderbank, "Space-time block coding for wireless communications: Performance results," IEEE J. Sel. Areas Commun., vol.17, no.3, pp.451–460, March 1999.

[6] N. Cornillet, M. Crussiere, and J.-F. Helard, "Performance of the DVB-T2 system in a single frequency network: Analysis of the distributed Alamouti scheme," 6th IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB2011), Nürnberg, Germany, June 2011.

[7] M. Tormos, C. Tanougast, A. Dandache, P. Bretillon, and P. Kasser, "Performance evaluation of distributed Tarokh SFBC and Alamouti MISO for SFN DVB-T2 broadcast networks," 18th IEEE International Conference on Electronics, Circuits and Systems (ICECS2011), pp.583–586, 2011.

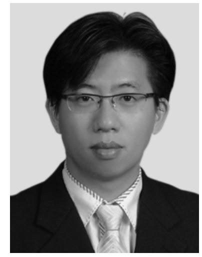
[8] M. Tormos, C. Tanougast, P. Kasser, P. Bretillon, and A. Dandache, "Performance evaluation for different MISO - SFN network combinations for DVB-T2 standard," 6th IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB2011), Nürnberg, Germany, June 2011.

[9] J. Arenas, T. Jokela, U. Gil, P. Angueira, D. De La Vega, D. Guerra, and I. Cascon, "Evaluation of the distributed MISO gain for mobile broadcast planning in real scenarios," 7th IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB2012), Seoul, Republic of Korea, June 2012.

[10] M. Tormos, C. Tanougast, A. Dandache, P. Bretillon, and P. Kasser, "Experimental performance of mobile DVB-T2 in SFN and distributed MISO network," 19th International Conference on Telecommunications (ICT2012), pp.1–5, 2012.

[11] European Broadcasting Union, “Frequency and network planning aspects of DVB-T2,” Technical Report TECH 3348, May 2011.
[12] J. Qi, J. Robert, K.L. Chee, M. Slimani, and J. Zoellner, “DVB-T2 MISO field measurements and a calibrated coverage gain predictor,” 7th IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB2012), pp.1–6, Seoul, Republic of Korea, June 2012.
[13] S. Jeon, J.-Y. Choi, Z. Yim, and J.-S. Seo, “Error floor analysis of signal space diversity schemes under erasure effect in single frequency network,” IEEE Trans. Broadcast., vol.58, no.3, pp.508–513, Sept. 2012.
[14] R.V. Hogg and A.T. Craig, Introduction to mathematical statistics, Macmillan, 1995.
[15] M.K. Simon and M.-S. Alouini, Digital communication over fading channels, 2nd ed. Wiley, 2005.
[16] S. Jeon, H.J. Ryu, I. Kyung, and M.-S. Kim, “Cooperative local area contents transmission within single frequency broadcast networks,” 58th Annual IEEE Broadcast Symposium (ABS 2008), Alexandria, VA, USA, Oct. 2008.
[17] Y.-W. Suh, S.I. Park, H.-K. Mok, H.M. Kim, J.-Y. Choi, and J.-S. Seo, “Network design and field application of ATSC distributed translators,” IEEE Trans. Broadcast., vol.56, no.2, pp.150–159, June 2010.
[18] A. Vigato, S. Tomasin, L. Vangelista, V. Mignone, N. Benvenuto, and A. Morello, “Coded decision directed demodulation for second generation digital video broadcasting standard,” IEEE Trans. Broadcast., vol.55, no.3, pp.607–615, Sept. 2009.
[19] A.H. Feiveson and F.C. Delaney, “The distribution and properties of a weighted sum of chi suqares,” NASA Technical Note D-4575, May 1968.
[20] “Advance coverage prediction software,” CRC-COVLAB [Online]. Available: http://www.crc.gc.ca/covlab/

Sungho Jeon received the B.S. (with Honors) and M.S. degrees in electrical and electronics engineering from Yonsei University, Seoul, Korea, in Aug. 2005 and Feb. 2007, respectively. Since March 2007, I have been with the Technical Research Institute at Korean Broadcasting System (KBS), where he is currently a Research Engineer. From March 2011, he pursues a Ph.D. degree in electrical and electronics engineering with emphasis on 4K UHDTV terrestrial digital broadcasting systems at the Yonsei University, Seoul, Korea.



Jong-Seob Baek received the M.S. and Ph.D. degrees in electrical and electronics engineering from Yonsei University, Seoul, Korea, in 2003 and 2007, respectively. From April 2010 to March 2011, he was with the Georgia Institute of Technology, Atlanta, in a post-doctoral position. From April 2011 to July 2012, he was with Yonsei University as a Research Professor. Since September 2012, he has been with the Team of Advanced Technology and System, Convergence Laboratory, CTO, LG Electronics, as a Chief Senior Engineer. His current research interests include advanced digital signal processing and analysis, such as synchronization, channel estimation, channel equalization for future broadband wireless multimedia broadcasting and communication systems.

Junghyun Kim received the B.S. and M.S. degrees in electronics engineering from Yonsei University, Seoul, Korea, in Feb. 2006 and Feb. 2008, respectively. Since March 2008, he has been with the Technical Research Institute at Korean Broadcasting System (KBS), where he is currently a Research Engineer. His main research interests include the development of database for integrated RF measurement and analysis system.

Jong-Soo Seo received the B.S. degree in electronics engineering from Yonsei University, Korea in 1975, and M.S. and Ph.D. degrees from the University of Ottawa, Canada in 1983 and 1988, respectively. He worked for IDC and CAL, Canada, for digital satellite communications and data broadcasting systems for six years. Since 1995, he has been with the Department of Electrical and Electronics Engineering at Yonsei University, Korea, where he is a professor. He was a director of Center for Advanced Broadcasting Technology from Nov. 2001 to April 2010. His current research interests include multimedia broadcasting systems. Since 2007, he has been an associate Editor for the IEEE Transactions on Broadcasting. Since Jan. 2009, he has been an advisory committee member of Korea Communications Commission (KCC).