Cooperative Local Area Contents Transmission within Single Frequency Broadcast Networks

Sungho Jeon, Ho Jin Ryu, Ilsoo Kyung, Man-Sik Kim

Broadcast Technical Research Institute (BTRI) in Korean Broadcasting System (KBS)
18 Yoido-dong Youngdeungpo-gu, Seoul, 150-790, Republic of Korea
{jeonsh, hana, iskyung, kms}@kbs.co.kr

***Abstract*— An improved local contents transmission technique is described in this paper. Delivery of local area contents can be done using centralized architectures in order to provide both global and local contents within an SFN (Single Frequency Network). Although local services would be redundantly transmitted in regions where they are not required, adopting a cooperation concept for transmitting local area contents preserves an advantage of SFNs as well as that of the cooperative transmission. The proposed technique does not require an additional frequency and service coverage adjustment. Simulation results show that the cooperative local area contents transmission within an SFN can improve the robustness of the broadcasting service, in particular, in the overlapping area. Among the three different cooperative transmission schemes, the SFBC-based scheme is applicable to local area contents transmission.**

I. Introduction

In order to provide good reception quality which is a key to broadcast service, the SFN (Single Frequency Network) is a solution that increases broadcast signal quality and signal density [1],[2]. Each region could be covered using one frequency which is broadcasted by multiple transmitters. That is, transmitters belonging to the same SFN regions deliver global contents over the same frequency at the very same time by radiating the identical RF (Radio Frequency) signals. Any receiver located in the area covered by the SFN will receive signal from one transmitter, or another without any difference, and moving from an area covered by one transmitter to another within the same SFN cell is transparent at the reception level. An SFN also guarantees reception in specific areas that one transmitter is not able to cover such as shadow areas at a building in a typical urban setting.

Recently, the need for transmitting local content has emerged due to the lack of available frequencies although the demand for location-based services is steadily increasing. According to [3], management and delivery for local area services can be done using centralized or distributed architectures, depending on the broadcast network's characteristics such as the deployed distribution network. Although each type of architecture has its specific benefits and limitations, if we utilize centralized architectures by employing multiple transmitters belonging to an SFN as multiple array antennas we achieve a so-called distributed MIMO (Multiple Input Multiple Output).

Several related works were performed [4]-[6], which mainly focused on avoiding interference caused by co-channel interference. A common problem for which solutions were suggested in previous works is a loss of SFN gain, which leads to additional coverage adjustment and causes the degradation of the received signal strength at the overlapping area.

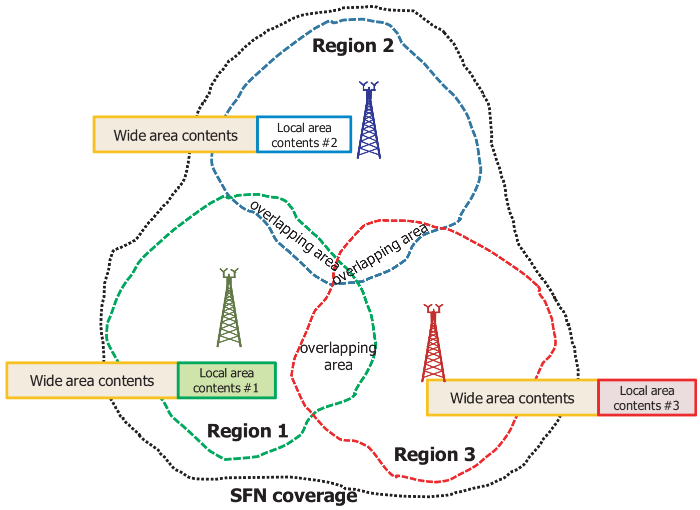

Fig. 1. Localized areas within single frequency broadcast network covered by multiple transmitters

The use of transmit diversity has been suggested as a new solution to alleviate the effect of deep fading in an SFN as well as to achieve the spatial diversity gain [7],[8]. Transmit diversity has originated from the fact that using multiple transmitters as a distributed antenna array can be efficient and full spatial diversity gain can be additionally achieved. In addition a receiver is able to get independent signals from several transmitters in an SFN, which provides a low probability of experiencing deep fading simultaneously. Therefore, the goal of this paper is to propose a new cooperative transmission scheme for broadcast networks that enables both global and local content transmission as well as obtaining SFN gain.

The paper is organized as follows. In Section II, previous works and the motivation for this work is outlined. In Section III, the cooperative local area contents transmission based on transmit diversity is explained. Simulation results are presented in Section IV, and finally Section V concludes this paper.

II. Previous Works and Motivation

A. Localized Area within SFN

SFNs are typical for digital broadcast systems in sending out identical global contents. An SFN is a broadcast network where several transmitters simultaneously send the same signal over the same frequency channel. The advantages of SFNs are efficient utilization of the radio spectrum, increasing coverage and decreasing the outage probability when compared to an MFN (Multiple Frequency Network), because the total received signal strength may increase in the overlapping area which is the border of coverage in an MFN, the so-called SFN gain. In addition, moving from an area covered by one transmitter to another within the same SFN is transparent at the reception level, which supports seamless handover.

As shown in Fig. 1, provisioning local services for localized areas within an SFN has other merits by combining the advantages of SFNs and MFNs. If both global and local services can be deployed in an SFN, it could provide the local service using only a single transmission frequency without requiring additional frequencies, and signals can be sent out using any subset of transmitters of the network in a cost efficient way. Therefore, it is possible to have a partial reuse of global capacity within an SFN and provide more flexibility in planning service coverage.

Consider as a problem, a service provider would like to provide different local contents dedicated to localized areas of the SFN and provisioning for local services is not possible because different local services sending out on a single frequency would interfere and corrupt reception with non-constructive signal superposition particularly at the overlapping area. A trivial solution to overcome this problem is to use an MFN that enables the transmission of local services but needs a significant amount of frequencies which require large amounts of valuable spectrum. In addition, more transmitters are needed than those of SFNs to cover the same region due to the lack of SFN gain, which requires adjusting each of the local service coverage additionally.

B. Survey on Previous Works

Several previous works proposed two similar solutions, and mainly focused on avoiding interference caused by co-channel interference. Therefore, the solution for coexistence of global and local services in one SFN is based on one or more radio resources reserved and dedicated to local services.

1) Time Division Transmission: A solution proposed in [4], [5] is that one or more timeslots in the time domain are reserved and allocated to each local service. When one transmitter delivers the local area content for its localized area during the reserved timeslot, other transmitters could not transmit their local area contents simultaneously as shown in Fig. 2 (a). It is important that only a single local area content allowed to transmit is carried exclusively during a timeslot period within the whole network, and the receiver extracts only the required local area content from the transmitted signal.

In [4] based on DAB (Digital Audio Broadcasting) standard, MSC (Main Service Channel) is partitioned into two parts:

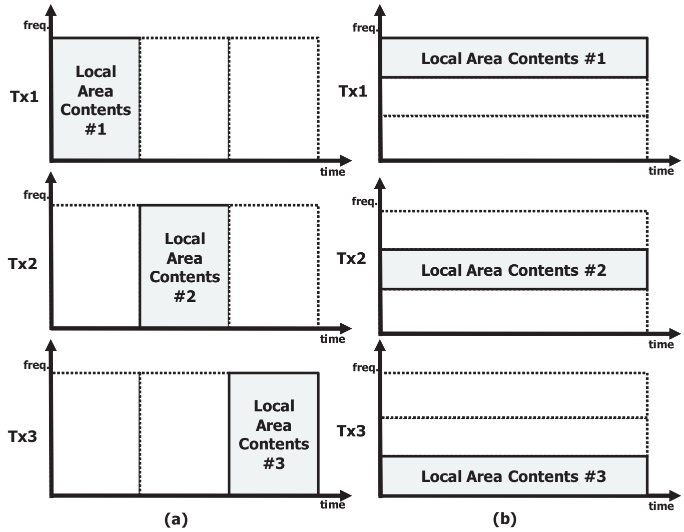

Fig. 2. Local area contents transmission using (a) Time division (b) Frequency division

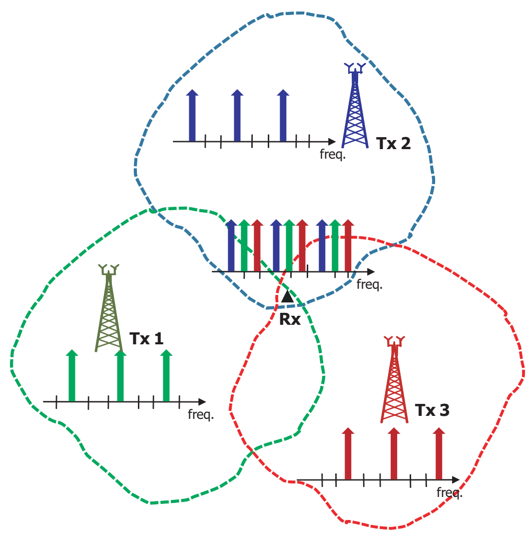

Fig. 3. Subcarrier collision avoidance for transmitting the local area contents over frequency domain

global and local. The local part is the remainder of the global part, which is used to deliver local area contents by allocating sub-channels over the time domain. This was performed as field trials in Dresden, Germany, and was reported that the experiments with local windows in DAB were done successfully.

In [5] based on DVB-H (Digital Video Broadcasting for Handheld) standard, the idea is to send data in bursts using a higher bit rate compared to the constant low bit rate. Within the current burst allowed local area content only could be transmitted. By using this technique, it is ensured that interference caused by different local services do not affect the global services and other local services. In order to guarantee that no data from the global services is mixed with data, from the local services, the adaptation intervals contain stuffing data which

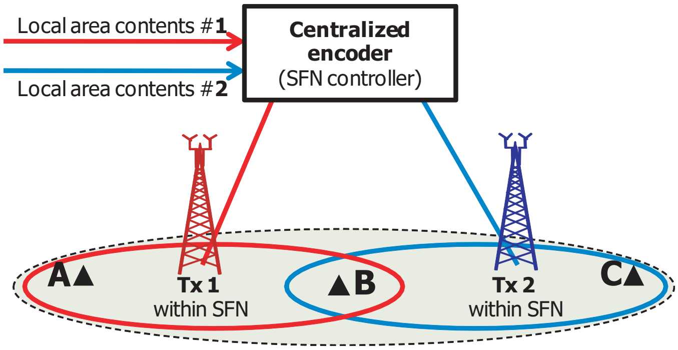

Fig. 4. An SFN consists of two transmitters, and each transmitter has a localized area to itself.

are identical for all the transmitters of the network is defined. The interference zone is also defined to prevent overlapping by adjusting transmit radiated power level at the individual transmitter. Because reception would not be possible if the signals of two or more transmitters transmitting different local services are superpositioned.

2) Frequency Division Transmission: Another solution is proposed in MediaFLO air interface standards [6]. Similarly, an individual subband over frequency domain is reserved for each local service as shown in Fig. 2 (b). When one transmitter delivers the local area content for its localized area through an allocated subband, other transmitters should not occupy this subband to transmit their local area contents simultaneously. Only one local area content is permitted to transmit exclusively in the subband within the whole network.

To easily understand the method on delivering local services in MediaFLO, the snapshot illustration at a certain timeslot is provided in Fig. 3. The occupied interlace, a subset of subcarriers that are evenly spaced across the bandwidth by a transmitter, is not used in any other transmitters. Consequently, interference caused by subcarrier collision does not occur due to coordinately allocated subcarriers to each transmitter. At the receiver side, the desired local area contents can be extracted by demodulating only the required subset of interlaces.

III. Cooperative Transmission with Multiple Transmitters in an SFN

The common problem, for which solutions were suggested in previous works is a loss of SFN gain, which leads to additional coverage adjustment and causes the degradation of the received signal strength at the overlapping area. The key concept of the proposed techniques is 'COOPERATION' in transmitting the local contents. Although local services would be redundantly transmitted in regions where they are not required, adopting the cooperation concept for transmitting local area contents would preserve the advantages of SFNs as well as that of cooperative transmission.

For an explanation of the proposed technique, the case of two transmitter transmission is depicted in Fig. 4, assuming that two local area contents should be delivered into an SFN. Within an SFN, s_i is the transmitted symbol corresponding to local area contents i. Each transmitter on different sites is simultaneously controlled, which transmit broadcast data coordinated by a centralized encoder.

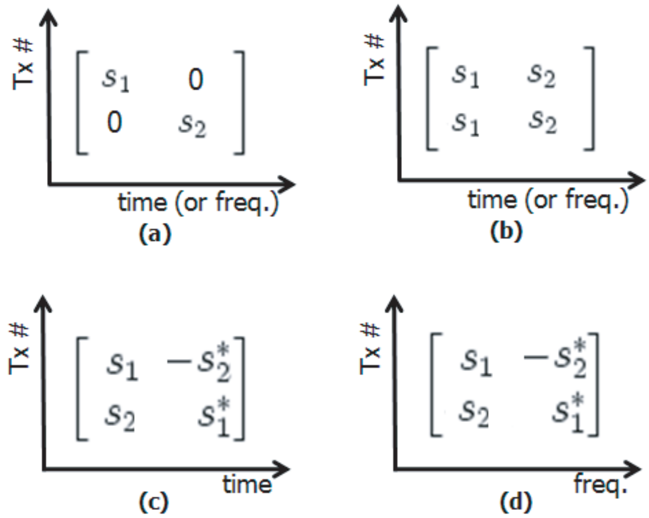

Fig. 5. (a) Conventional transmission (b) Plain (c) STBC-based (d) SFBC-based cooperative transmission

A. Plain Cooperative Transmission

In the conventional scheme, a certain timeslot or subcarrier should be occupied by one transmitter allowed to transmit, and all other transmitters should be mute during a period or at a frequency as shown in Fig. 5 (a).

In contrast, if the plain cooperative transmission is used as depicted in Fig. 5 (b), the transmitter responsible for the current local area content is not only carrying out the symbol but also others not related to this local area content are involved in transmitting it. All transmitters transmit an identical symbol as if transmitting wide area contents in an SFN. In Fig. 5 (b), at time t_1 (or frequency f_1), s_1 is simultaneously transmitted from the two separate transmitters composed of an SFN. At the next symbol period t_2 (or frequency f_2), s_2 is simultaneously transmitted.

B. STBC-based Cooperative Transmission

The space-time block code (STBC) is a simple example of a space-time code [9]. In the case of two transmitter transmission as depicted in Fig. 5 (c), the Alamouti encoding rule is applied over the time domain. At the transmitter the sequence of symbols to transmit is split into two streams and coded. If s_1 and s_2 are two symbols to transmit, then at time t, s_1 and s_2 are simultaneously transmitted from the two transmitters involved in an SFN. At the next symbol period $t+T$, $-s_2^*$ and s_1^* are simultaneously transmitted, where s_i^* is the conjugate complex of s_i.

C. SFBC-based Cooperative Transmission

Similarly, the space-frequency block code (SFBC) can be applied across two neighboring OFDM subcarriers within a single OFDM symbol duration [10], [11]. As shown in Fig. 5 (d), the Alamouti encoding principle is applied over frequency domain. At frequency f, s_1 and s_2 are simultaneously transmitted from the two transmitters in an SFN. At the next subcarrier $f + \Delta f$, $-s_2^*$ and s_1^* are simultaneously transmitted where Δf is the subcarrier spacing chosen to be orthogonal.

In sum, although local services would be redundantly transmitted in regions where they are not required, the proposed cooperative transmission has some advantages as follows:

- without loss of SFN gain as well as cooperative diversity gain using given bandwidth
- additional adjustment of service coverage not required
- controlled as a centralized architecture
- data rates allocated for local area contents transmission are equal to that of a conventional technique

D. Case Study for Cooperative Transmission

To confirm the feasibility of cooperative transmission, an environment is considered as depicted in Fig. 4. An SFN is designed with two transmit sites that are located over a line, and it is assumed that a receiver with one receive antenna can be randomly located over the whole SFN coverage.

The receiver's reference location is assumed to be at point A, B and C. It can be also assumed that each receiver at point A and C can only receive one signal from Tx1 and Tx2, respectively. In contrast, the receiver at point B simultaneously receives two signals from both transmitters.

1) Plain Cooperative Transmission: At all points, the receiver decodes the received signal based on conventional method. If the desired local area contents are transmitted in certain timeslots, the receiver wakes up and decodes the signal. If undesired data is transmitted, however, the receiver ignores this signal transmitted in other timeslots.

2) STBC-based and SFBC-based Cooperative Transmission: Assume that the received signal at point R in time (or frequency) i is R_i. The received signal at each point can be represented as (1), (2) and (3).

$$
\begin{aligned}
A_1 &= h_{1,A}x_1 + n_{1,A} && (1)\\
A_2 &= -h_{2,A}x_2^* + n_{2,A} \\
B_1 &= h_{1,B}x_1 + h_{2,B}x_2 + n_{1,A} && (2)\\
B_2 &= -h_{1,B}x_2^* + h_{2,B}x_1^* + n_{2,B} \\
C_1 &= h_{2,C}x_2 + n_{1,C} && (3)\\
C_2 &= h_{2,C}x_1^* + n_{2,C}
\end{aligned}
$$

where x_i is the transmitted signal from Tx i, $h_{i,j}$ is the channel coefficient between Tx i and the receiver at point j and $n_{i,j}$ is the noise in timeslot (or frequency) i at the point j.

Using the combining scheme suggested in [9] without any modifications, the received signal can be detected as (4), (5) and (6), then sent to the maximum likelihood detector.

$$
\begin{aligned}
\hat{x}_{1,A} &= A_1 h_{1,A}^* = |h_{1,A}|^2 x_1 + n_{1,A}h_{1,A}^* && (4)\\
\hat{x}_{2,A} &= -A_2^* h_{1,A} = |h_{1,A}|^2 x_2 - n_{2,A}^* h_{1,A} \\
\hat{x}_{1,B} &= B_1 h_{1,B}^* + B_2^* h_{2,B} && (5)\\
&= (|h_{1,B}|^2 + |h_{2,B}|^2)x_1 + n_{1,B}h_{1,B}^* + n_{2,B}^* h_{2,B} \\
\hat{x}_{2,B} &= B_1 h_{2,B}^* - B_2^* h_{1,B} \\
&= (|h_{1,B}|^2 + |h_{2,B}|^2)x_2 + n_{1,B}h_{2,B}^* - n_{2,B}^* h_{1,B} \\
\hat{x}_{1,C} &= C_2^* h_{2,C} = |h_{2,C}|^2 x_1 + n_{2,C}^* h_{2,C} && (6)\\
\hat{x}_{2,C} &= C_1 h_{2,C}^* = |h_{2,C}|^2 x_2 + n_{1,C}h_{2,C}^*
\end{aligned}
$$

where $\hat{x}_{i,j}$ is the decoded signal of Tx i at point j.

Consequently, cooperative local area contents transmission within an SFN is obviously feasible at each point without any changes of an original technique though the diversity gain cannot be fully achievable at point A and C. Note that utilizing transmitter identification (TxID) makes the decoding process more stable.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Modulation	16QAM
Bandwidth	6MHz
Total number of subcarriers	4096
Ratio of cyclic prefix	1/4
Channel model	COST207 TU-6
Maximum Doppler frequency	10Hz, 100Hz
Error correction code	Uncoded
Channel estimation	Perfect

IV. SIMULATION RESULTS

In Table I, some major simulation parameters are listed. As described in Fig. 4, it is assumed that an SFN is made up of two transmitters, and each of the transmitters has a localized area to itself. To reflect a receiver location, the received signal power ratio is defined as P_1/P_2 where P_i is the received signal power from Tx i.

Figure 6 and 7 show the uncoded BER (Bit Error Ratio) according to the SNR (Signal to Noise power Ratio) and three different techniques for transmitting local area contents are presented for comparison.

In Fig. 6 and 7, using the plain cooperative transmission, a 3dB gain can be obtained compared to the conventional technique in which only a single transmitter is involved in transmitting local area contents. This 3dB gain is equal to the amount of SFN gain due to mutual support of the signals from multiple transmitters. By exploiting STBC or SFBC concept, an additional gain can also be achieved compared to the plain cooperative transmission. This gain stems from the spatial diversity based on Alamouti code such as STBC and SFBC.

Because STBC assumes that the channel responses are constant during the two time slots, the performances of STBC-based scheme along the time domain is worsened as the

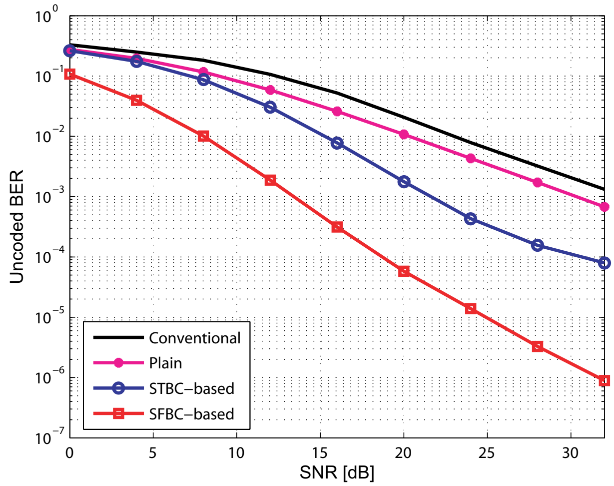

Fig. 6. BER performance comparison according to SNR as a function of different local area contents transmission techniques when Doppler frequency is fixed to 10Hz (received signal power ratio = 0dB)

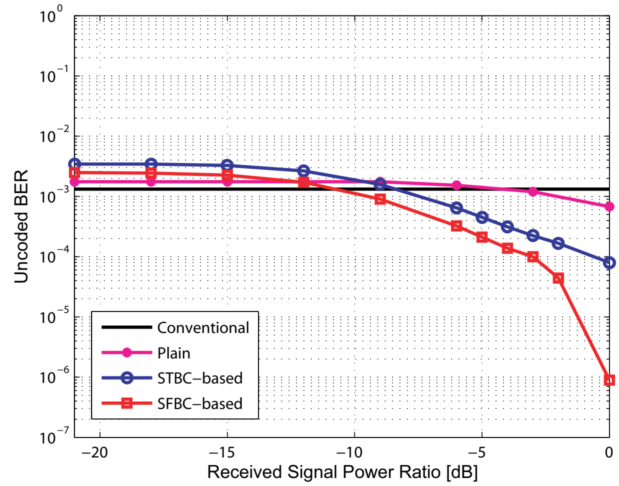

Fig. 8. BER performance comparison according to received signal power ratio as a function of different local area contents transmission techniques (Doppler frequency = 10Hz, SNR = 32dB)

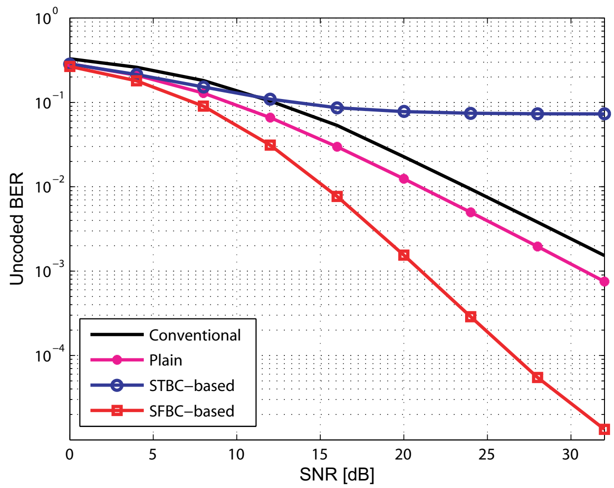

Fig. 7. BER performance comparison according to SNR as a function of different local area contents transmission techniques when Doppler frequency is fixed to 100Hz (received signal power ratio = 0dB)

Doppler frequency increases, even in case of the conventional scheme. Error floor effect is observed in the case of STBC because the channel varies during two successive OFDM symbol periods. In contrast, SFBC assumes that the complex channel gains between adjacent subcarriers are approximately identical and therefore SFBC-based scheme works well at both low (10Hz) and high (100Hz) Doppler frequency and is applicable to a broadcasting system in fast fading.

Figure 8 represents the uncoded BER according to the received signal power ratio when SNR is fixed to 28dB. An increase of received signal power ratio means that a receiver is approaching the overlapping area, which situates the receiver's move from a point A to a point B in Fig. 4. With the decrease of received signal power ratio leads to performance degradation in case of one transmitter. As the receiver cannot obtain the signal from both transmitters as represented in (4) and (6), the transmit diversity is not fully utilized if the receiver is located in a point A or C as shown in Fig. 4. Therefore, the performance approaches to that of the conventional technique by decreasing the receiver signal ratio.

Consequently, although the cooperative transmission causes the redundancy in localized areas where they are not required, the performance can be enhanced using the proposed technique without adjusting service coverage compared to a conventional technique described in Section II. Thus, the introduction of a cooperative transmission for local area contents transmission is required for performance enhancement. Among the three different cooperative transmission schemes, the SFBC-based scheme is suitable to local area contents transmission as shown by simulation. In contrast, it was also shown by simulation that STBC-based scheme is not applicable due to severe performance degradation as Doppler frequency increases.

V. Conclusion

An improved local contents transmission technique is proposed without an additional frequency and service coverage adjustment. Local area contents delivery can be done using centralized architectures in order to provide both global and local contents within an SFN. Although local services would be redundantly transmitted in regions where they are not required, adopting a cooperation concept for transmitting local area contents preserves an advantage of SFNs as well as that of cooperative transmission. Simulation results show that the cooperative local area contents transmission within an SFN can improve the robustness of the broadcasting service, in particular, in the overlapping area. Among the three different cooperative transmission schemes, the SFBC-based scheme is applicable to local area contents transmission as proven by simulation.

References

[1] G. Malmgren, "On the performance of single frequency networks in correlated shadow fading," *IEEE Trans. on Broadcasting*, vol. 43, no. 2, pp. 155-165, June 1997.

[2] A. Mattsson, "Single Frequency Networks in DTV," *IEEE Trans. on Broadcasting*, vol. 51, no. 4, pp. 413-422, December 2005.

[3] R. Lhermitte, "Local and Ultra Local Content in Broadcast Mobile TV," *NAB Broadcast Engineer Conference 2008*, Las Vegas, NV, USA, April 2008.

[4] C. Albinus, M. Strey and H.-J. Nowottne, "Experiments with Local Windows in DAB," *Proceedings of the Third International Symposium on Digital Audio*, Montreux, June 1996.

[5] G. May and P. Unger, "A New Approach for Transmitting Local Content within Digital Single Frequency Broadcast Networks," *IEEE trans. Broadcasting*, vol. 53, no. 4, pp. 732-737, December 2007.

[6] TIA-1099, FLO Air Interface Specification Rev. 1.0, 2007.

[7] J.-T. Wang, J. Song, J. Wang, C.-Y. Pan, Z.-X. Yang and L. Yang, "A General SFN Structure with Transmit Diversity for TDS-OFDM System," *IEEE trans. on Broadcasting*, vol. 52, no. 2, pp. 245-251, June 2006.

[8] C. Qu, J. Yang and G. Zhang, "Virtual MIMO-based Single Frequency Network," *Proc. IEEE ICC*, pp. 2012-2016, Beijing, China, May 2008.

[9] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE J. Sel. Areas Comun.*, vol. 16, no. 8, pp. 1451-1458, October 1998.

[10] K. F. Lee and D. B. Williams, "A Space-Frequency Transmitter Diversity Technique for OFDM Systems," *Proc. IEEE GLOBECOM*, vol. 3, pp. 1473-1477, San Francisco, CA, November 2000.

[11] S. Kaiser, "Space Frequency Block Codes and Code Division Multiplexing in OFDM Systems," *Proc. IEEE GLOBECOM*, vol. 4, pp. 2360-2364, San Francisco, CA, November 2003.

[12] COST 207, "Digital Land Mobile Communications (Final Report)," Commission of the European Communities, Directorate General Communications, Information Industries and Innovation, pp. 135-147, 1989.