Planning of Gap Filler Networks in Satellite DMB Systems for Wireless Multimedia Services

Sun Kuk Noh, Tae Soon Yun, and Dong You Choi

Abstract: **Satellite digital multimedia broadcasting (S-DMB) systems use gap fillers (GFs) to provide wireless multimedia services to non-line-of-sight locations. GFs act as repeaters, and S-DMB systems require GF networks in order to guarantee mobile reception. Each GF covers a cell or sector. In order to provide contiguous coverage of an area comprising two or more cells or sectors, multiple GFs are needed. However, when multiple GFs are situated close to each other, interference is likely to occur. As a result, in this study, we have investigated system-level environments for planning the design of interference-free GF networks in S-DMB systems. Our investigations revealed that S-DMB services are unavailable because of quality deterioration caused by interference when the delay attributable to a GF and the satellite signals exceeds ± 256 chips and the distance between the GF and its reception terminal is greater than 4.6 km. On the basis of this analysis, we conducted a field test that confirmed that the above-mentioned time delay can be controlled in such a way as to ensure high quality S-DMB services.**

Index Terms: **Gap filler (GF), interference, satellite digital multimedia broadcasting (S-DMB), time delay, wireless multimedia service.**

I. INTRODUCTION

Mobile communication and data transmission technologies have rapidly developed in recent years. With the launch of digital broadcasting facilitated by digital technology, communication-broadcasting convergence has also emerged as an exciting topic of interest. In Europe, studies on digital audio broadcasting (DAB) have been actively conducted since the 1990s. As a result, audio and data services have already been deployed [1]–[4]. These early-stage global services can be categorized as satellite digital multimedia broadcasting (S-DMB) and terrestrial DMB (T-DMB) services. S-DMB is a personal digital medium that can provide bidirectional and interactive services via a convergent platform of broadcasting and communication [5], [6]. It provides high quality services, which can be accessed at any time and form anywhere, to vehicles moving at speeds of up to 300 km/h. For S-DMB services, the most serious problem is the deterioration of signals due to shadowing. It is not always possible to maintain line-of-sight (LOS) radio paths between the satellite and user terminal because of shadowing due to buildings, tunnels, and other natural conditions. S-DMB thus utilizes gap fillers (GFs) to provide service to areas that cannot receive the satellite signal directly because of obstructions, i.e., non-LOS (NLOS) areas [7]. The GF acts as a repeater and GF networks for S-DMB systems are constructed and utilized in order to guarantee mobile reception. As each GF covers a defined area called a cell or sector, interference is likely to occur when multiple GFs are situated close to each other in an effort to provide contiguous coverage.

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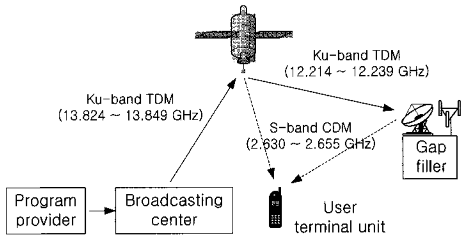

Fig. 1. Korea S-DMB system architecture.

In this study, we investigated system-level environments for planning the design of interference-free GF networks. Elements of our investigation include the wave propagation model, S-DMB channel models, minimum search-window size of the user terminal unit (Rx),interference in the boundary region of a GF and S-DMB satellite, field tests, and analysis. Our analysis confirmed that the time delay attributable to a GF and the satellite signal can be controlled in order to maintain a high quality of service.

II. SATELLITE DMB SYSTEM

A. System E Satellite DMB

S-DMB is a new service that allows subscribers to access multimedia broadcast channels at any time and from anywhere via special receivers in mobile handsets and automobiles. Users can freely access a variety of multimedia content such as video, voice, and data using personal portable devices or mobile devices for vehicles. Mobile phone and internet services are available as well. The S-DMB system is capable of offering varying levels of multimedia quality, including high-quality multimedia comparable to that obtained from digitally recorded consumer media. It can also offer various data services and different levels of conditional access as well as the capability to dynamically rearrange the various services contained in the multiplexed signal. The DMB frequency spectrum is jointly managed by Korea and Japan. In Korea, the upper frequency band of S-DMB is specified as System E S-DMB. These specifications are listed in Table 1.

The system architecture for the Korea S-DMB is shown in

Table 1. Specifications for System E of satellite DMB.

Country	Korea, Japan
Standard	System E
Transfer technology	CDM
Transfer rate	9.44–16.52 Mbps
Bandwidth	25 MHz (Max.)
Video compression	MPEG-4 AVC part 10, H.264 baseline level 1.3
Audio compression	MPEG-2 AAC
Error correction	RS code (204,188), convolution code
Modulation	DS-CDM BPSK/QPSK
Per channel data rate	256 kbit/s
Spread code	64 bit Walsh code
Chip rate	16.384 Mchip/s
Frequency band	2630–2655 MHz
Frequency use efficiency	0.4–0.7
Number of channels	30 or more

Fig. 1. There are two signal paths to the user terminals. One is a direct reception path from the satellite, while the other is a relay path through terrestrial GFs. The direct-path downlink signal to the user terminals uses the S-band code-division multiplexing (CDM) format. The relay-path feeder link signal to the terrestrial GF uses the Ku-band time-division multiplexing (TDM) format. This format is converted to the S-band CDM format before the retransmission of the S-DMB signals to the user terminals.

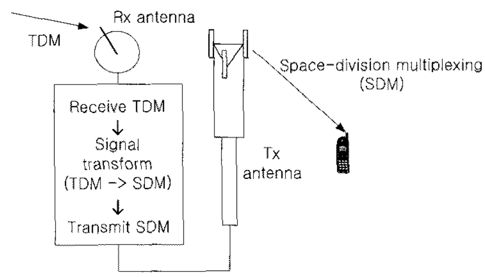

Fig. 2. GF system.

B. Gap Fillers

A GFs consists of a parabolic antenna that receives the Ku-band TDM signals from the satellite and converts them into CDM signals, as illustrated in Fig. 2. GFs in an S-DMB system are analogous to the base stations in a cellular phone network. However, satellites already provide much coverage, even in urban areas where user terminals may receive direct or relay-path signals in shadowed or blocked areas such as subways, tunnels, and near inside buildings. In order to solve the problem of receiving S-DMB service in an area where signal propagation is obstructed, a single cell or sector, analogous to similar elements in a mobile phone network, is formed at the establishment of the GF system.

III. SYSTEM-LEVEL ENVIRONMENTS

A. Wave Propagation Model

The propagation model employed is a free-space model in the LOS condition (satellite-Rx), and an extended Hata model in the NLOS condition (GF-Rx).

(1) Free space model: The propagation model employed in LOS condition is the free space model. This model can be expressed as follows.

$$PL = 32.5 + 10\log\left(\left(\frac{h_{tx}-h_{rx}}{1000}\right)^2 + d^2\right) + 20\log f \approx 32.5 + 10\log d^2 + 20\log f \quad (1)$$

where h_{tx} is the transmitter height (m), h_{tx} is the receiver height (m), d is the transmitter-receiver separation, and f denotes the transmitter frequency.

(2) Extended Hata model: The path loss model of the DMB systems-level simulation, obtained originally from the extended Hata model, is applicable to test scenarios in urban and suburban areas. Depending on urban and suburban distances, the path losses can be expressed as follows.

$$PL_{\text{urban}} = (46.3 + 33.9\log(f) - 13.82\log(h_b)) + (44.9 - 6.55\log(h_b))(\log d_1) - a(h_m) \quad (2)$$

$$PL_{\text{suburban}} = (46.3 + 33.9\log(f) - 13.82\log(h_b)) + \left(44.9 - 6.55\log(h_b)\log(d_1) - a(h_m) - 2\left(\log\left(\frac{f}{28}\right)\right)^2 - 5.4a(h_m)\right) = (1.1\log(f) - 0.7)(h_m) - (1.56\log(f) - 0.8)\text{ dB} \quad (3)$$

where d_1 is the transmitter-receiver separation, f denotes the transmitter frequency, h_b is the height of the base station or transmitter (30–200 m), h_m is the height of the mobile or receiver (1–10 m), and $a(h_m)$ is the mobile antenna correction factor.

(3) Path loss to 2.6 GHz: The simulation conditions are listed below, while the results are illustrated in Fig. 3.

- d is the transmitter (satellite)-receiver separation (36,000 km).

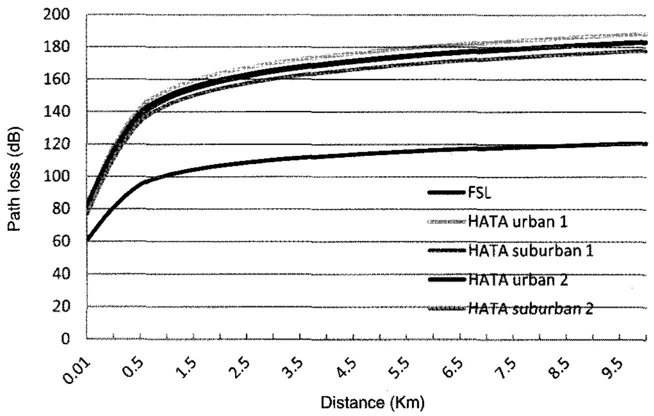

Fig. 3. Path loss to 2.6 GHz (h_b = 30 m, h_m = 1.5 m / h_b = 50 m, h_m = 2 m).

Table 2. S-DMB channel models.

Case	Portable reception	Mobile reception
1	1 path Ricean ($k = 8$ dB)	-
2	1 path Rayleigh	IMT-2000 6 path Rayleigh
3	2 path Ricean ($k = 10$ dB)	1 path Rayleigh
4	1 path Ricean ($k = 8$ dB)	IMT-2000 6 path Rayleigh

Table 3. Power delay profile of 6-path IMT-2000 channel.

Path	Relative delay (ns)	Relative power (dB)
1	0	−2.5
2	300	0.0
3	8,900	−12.8
4	12,900	−10.0
5	17,100	−25.2
6	20,000	−16.0

- d_1 is the transmitter (GF)-receiver separation (1–10 km).
- f denotes the transmitter frequency (2,600 MHz).
- h_b is the height of the base station or transmitter (30, 50 m).
- h_m is the height of the mobile or receiver (1.5, 2 m).

B. S-DMB Channel Models

S-DMB channel models, in accordance with [8], are listed in Table 2. The power delay profile of the 6-path international mobile telecommunications (IMT)-2000 channel is listed in Table 3. The bit-error-rate (BER) ($\leq 2 \times 10^{-4}$) of the S-DMB system allows the broadcasting of approximately 30 channels [6].

- Case 1. Only the downlink satellite signal is received.
- Case 2. Only the small coverage gap filler signal is received.
- Case 3. Only the large coverage gap filler signal is received.
- Case 4. Both the downlink satellite signal and the large coverage gap filler signal are received.

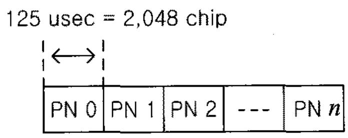

Fig. 4. Timing of CDM signal.

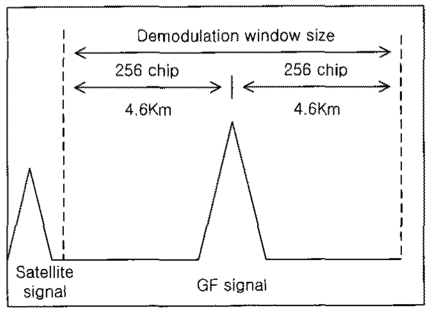

Fig. 5. Window size of terminal unit (Rx).

C. Minimum Size of Search Window for User Terminal Unit (Rx)

The chip rate of the pseudo-noise (PN) sequence in System E is 16.384 Mcps. The duration of one period is 2,048 chips, which is equivalent to 125 μs when measured in terms of time. The timing of the CDM signal is illustrated in Fig. 4.

A single symbol coincides with one PN period. If a receiver has access to two paths separated by more than 62.5 μs (half of a period), the receiver demodulates the two paths at different symbol times. In this case, adjacent symbols always interfere with each other. Assuming that the PN timing of a satellite signal should be aligned with that of the GF signal at the end point of the antenna without loss of generality and excluding multipath delay, the maximum possible time delay occurs at the cell edge between the satellite signal and GF signal. This time delay can be expressed as follows.

$$\begin{aligned}\text{Time delay (TD)} &= \text{TD}_{\text{Satellite-GF}} + \text{TD}_{\text{GF-Rx}} \\ &\quad - \text{TD}_{\text{Satellite-Rx}} \\ &= \frac{\text{Wave popagation distance } (d)}{\text{Wave velocity } (C)}.\end{aligned} \quad (4)$$

- Maximum multi-path time delay for System E: ±512 chips ($\pm 31.25\mu s$).
- Minimum size of search window for terminal unit: ±256 chips.
- Period: PN sequence–2,048 chips (= 125 μs).

If the distance between the GF and the terminal exceeds 4.6 km with a time delay of over 256 chips due to the GF and satellite signals, as shown in Fig. 5, the signal quality may deteriorate because of interference. As a result, the window size of the receiver terminal is limited to ±256 chips.

D. Interference in the Boundary Region of a GF and the S-DMB Satellite

The boundary area of the satellite and GF signals is illustrated in Fig. 6. In Rx(2), the satellite signal interferes with GF sig-

Table 4. Boundary area of satellite and GF signals.

Receiver (Rx)	Time delay (TD)	Prior receive signal	Receive state
Rx(1)	$0 < \mathrm{TD} < 256$	GF CDM	Good
Rx(2)	$\mathrm{TD} = 256$	GF CDM & satellite CDM receive	Poor (ghosts or monitor breaks)
Rx(3)	$\mathrm{TD} > 256$	Satellite CDM	Good

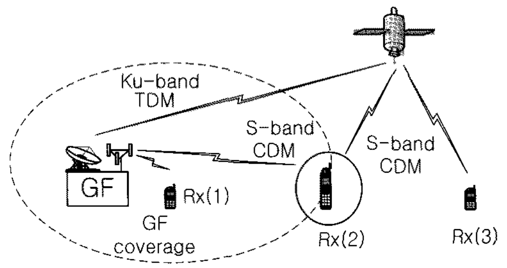

Fig. 6. Boundary area of satellite and GF signal.

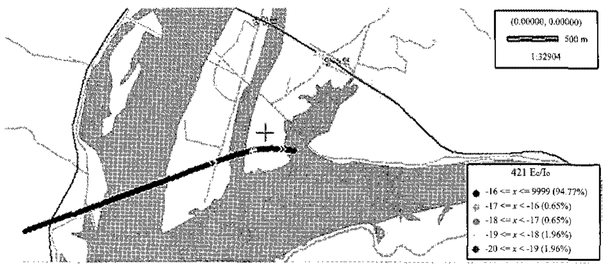

Fig. 7. Before: GF signal quality is 39.98% (max time delay delay: 0 chip (satellite), 0 chip (GF)): Results of field test (E_c/I_o).

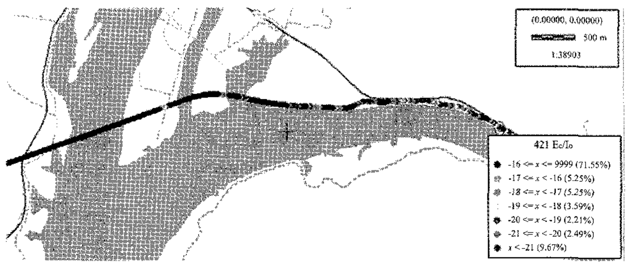

Fig. 8. After: GF signal quality is 58.96% (max time delay: 446 chip (satellite), 118 chip (GF)): Results of field test (Ec/Io).

nals that are beyond the boundary of the window size ($= \pm 256$ chips) of the receiver terminal. The signal quality for Rx(2) is listed in Table 4.

The adjacent channel interference ratio (ACIR) is mainly of interest in network simulations where the total amount of interference is above a certain minimum value. As the S-DMB system is a broadcasting communication system, it only has a down link (DL). The ACIR can be expressed as follows [9].

$$\mathrm{ACIR} = \frac{1}{\left(\frac{1}{\mathrm{ACLR}} + \frac{1}{\mathrm{ACS}}\right)} = \frac{(\text{Total Tx power})_{\text{Source BS or UE}}}{(\text{Total interference power})_{\text{Victim receiver}}} \quad (5)$$

The 3rd generation partnership project (3GPP) has introduced new terms pertaining to adjacent channel power (ACP). These include adjacent channel leakage power ratio (ACLR), and adjacent channel selectivity (ACS). The ACLR is a measure of transmitter performance. It is defined as the ratio of the transmitted power to the power measured at a point past a receiver filter in the adjacent RF channel. On the other hand, the ACS is a measure of receiver performance. It is defined as the receiver filter attenuation on the adjacent channel frequency. In contrast to both of these, the ACIR is a measure of the over-all power transmitted from a source (base station or Rx) to the total interference power affecting a victim receiver. It results from the imperfections in both the transmitter and receiver.

E. Field Test and Analysis

In the boundary area of the GF and satellite signals, i.e., where the signals overlap with one another, the received signal is of poor quality consisting of ghosts or monitor breaks. This being the case, we sought to improve the signal quality using the time delay attributable to the GF and satellite signals, and confirmed the results in a field test. For this test, the following devices were required: A parabolic antenna that receives Ku-band TDM signals from the satellite, a GF that converts TDM signals into CDM signals, a GF transmission antenna, a satellite DMB terminal, a simulation PC (to act as a mobile test device), and a spectrum analyzer.

The results of the field test are shown in Figs. 7 and 8. At the start of the test, before the time delay was controlled, the GF signal quality was 39.98%. However, after the delay was brought under control, the GF signal quality improved to 58.96%. The red and blue lines are the BERs of the received signals (x) with $5e^{-3} \leq x$ and $1e^{-3} \geq x$, respectively. From these results, it is clear, that the signal quality can be improved by controlling the time delay attributable to GF and satellite signals.

IV. CONCLUSION

Satellite DMB systems use GFs in order to make services available even in shadow areas (NLOS). GFs act as repeaters, and a GF network has to be established in oreder to enable a satellite DMB system to receive signals. When multiple GFs are set up close to each other in order to provide contiguous coverage to areas, problems such as interference may occur. In this study, we investigated system-level environments for planning the design of interference-free GF networks. We confirmed that the S-DMB service will be unavailable because of the quality deterioration caused by interference when the delay due to the GF and satellite signals exceeds ± 256 chips and the distance between a GF and the receiving terminal is greater than 4.6 km.

From our investigations, we found that the time delay due to the GF and satellite signals can be controlled in order to maintain a high quality of service.

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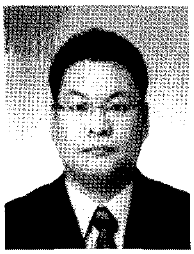

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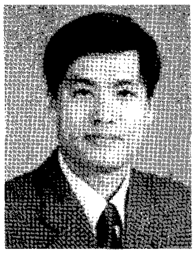

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