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Private 5G Radio Control Method for IPTV by Cable TV and Simulation Study

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Abstract

In relation to the hybrid MIMO scheme proposed by the authors, which multiplexes broadcast and communication streams over MIMO in private 5G, we study four radio control techniques: variable radio subcarrier spacing, dynamic TDD configuration, FWA-specific radio control functions and their parameter extraction, and radio resource block allocation for IPTV. Simulation experiments will reveal the improvement of transmission efficiency by MIMO for multi-dwelling units.

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Introduction

The introduction of private 5G to cable TV will contribute to the sustainable development of broadcasting and telecommunications infrastructure in local communities by improving disaster resilience, enabling flexible integration with existing infrastructure, and efficiently upgrading aging facilities. To utilize private 5G in cable TV, we are conducting research on frequency utilization efficiency technologies to realize multi-channel IPTV, including internet services, in the sub 6 GHz band (4.8 - 4.9 GHz). In this context, to achieve both the reliability required for IPTV and the efficiency of other communication data on Multiple Input Multiple Output (MIMO), we propose a hybrid MIMO scheme that multiplexes diversity MIMO (single layer) and multi-stream MIMO (multi-layer) [1,2].

In this study, as part of our research, we report on the radio control technologies applicable to both IPTV and other communication data including unicast video streams.

In Chapter 1, we introduce the hybrid MIMO multiplexing method that combines IPTV and communication data based on adaptive Multicast and Broadcast Service (MBS) defined by 3GPP, and summarize the advantages of Time Division Multiplexing (TDM) over Frequency Division Multiplexing (FDM) [3-5].

In Chapter 2, we discuss the technologies supporting the hybrid MIMO, including variable Sub-Carrier Spacing (SCS), which adjusts the SCS for IPTV streams and communication data streams as specified by 3GPP. We also examine the dynamic Time Division Duplex (TDD) configuration, which allows the DownLink (DL) and UpLink (UL) patterns of each slot to be dynamically changed for each radio frame and review the 3GPP-specified radio control functions and parameters specialized for Fixed Wireless Access (FWA).

In Chapter 3, we discuss two approaches to the allocation of radio resource blocks for IPTV based on the variable SCS and dynamic TDD radio controls.

In Chapter 4, the effectiveness of MIMO for IPTV is clarified from the results of the simulator analysis, which was developed using an apartment complex as a receiver model and incorporating radio parameters including MIMO and viewing parameters related to IPTV. In addition, the analytical formulas for the adaptive MBS, multicast and unicast were obtained for future comparative evaluation on 5G hybrid MIMO.

Materials and Methods

I. Adaptive MBS and MIMO Multiplexing

Adaptive MBS

In 3GPP Releases 17 and 18, MBS specifies both broadcast for macro cell with high power and distances exceeding several kilometers, which can be received without a SIM card, and multicast for small cell suitable for private 5G with distances of around a few hundred meters. Table 1 shows a comparison of MBS broadcast and MBS multicast.

Table 1: Comparison of MBS Broadcast and MBS Multicast

	MBS Broadcast	MBS Multicast
UE	All UEs within the coverage area	Authorized UEs within the coverage area
MIMO	1 layer(SISO)	Max 8 layers
Slot-level reputiton	Support	Not supported
Radio parameters	Set with SIB※1	Set with RRC※2 message
HARQ-ACK feedback	Not supported	Support

SIB※1 :System Information Block
RRC※2 :Radio Resource Control

The authors propose an adaptive MBS, as shown in Figure 1, which combines MBS multicast and unicast to enhance frequency utilization efficiency through MIMO and to support HARQ-ACK feedback.

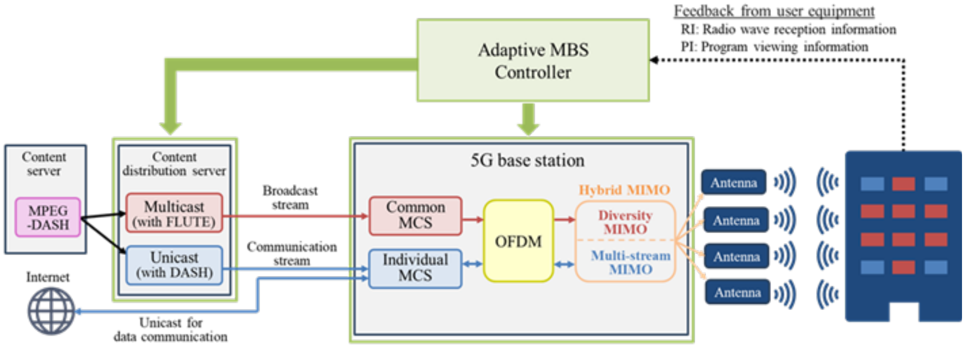

Figure 1: Configuration of Adaptive MBS

Specifically, the Modulation and Coding Scheme (MCS) common to all receiving households applied to the IP multicast stream is set as high as possible to maintain high frequency utilization efficiency. For households with poor reception environments that can only receive lower-order Quadrature Amplitude Modulation (QAM), unicast delivery with TCP packet retransmission is applied. Additionally, based on viewer information, multicast delivery is performed only for programs watched by two or more devices, dynamically switching with unicast delivery. The User Equipment (UE) synchronizes with the transmission-side switching and seamlessly switches playback between multicast and unicast through buffering of MPEG-DASH segments.

Hybrid MIMO Multiplexing

To achieve both the reliability of IPTV via multicast and the efficiency of communication data including unicast, we compared the multiplexing methods of FDM and TDM as shown in Figure 2. These multiplexing methods were evaluated based on 6 items listed in Table 2, and TDM was found to be superior in all aspects. Among these, transmission delay, TDD configuration, and variable SCS are particularly significant factors related to the TDM-based radio control discussed below.

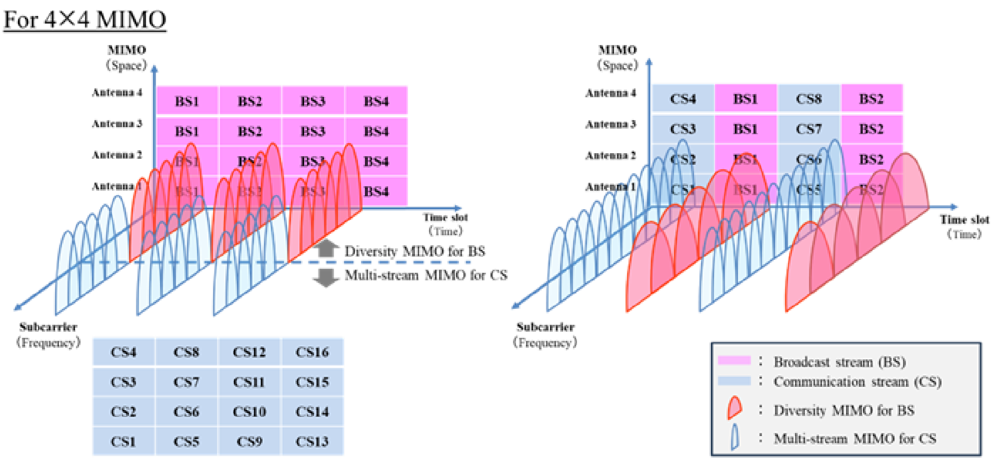

Figure 2: Concept of Hybrid MIMO

Table 2: Comparison of FDM and TDM

Item	FDM	TDM
MIMO effect	Time fluctuation ⇒Mobile Communication	Frequency selectivity ⇒FWA
Transmission delay	Large variance in time direction ⇒Large delay	Small variance in time direction ⇒Small delay
Scheduling accuracy	Unable to manage channel information at the same time ⇒Accuracy is low	Manage channel information at the same time ⇒Accuracy is high
TDD configuration	TDD pattern is fixed	TDD pattern is variable
MIMO precoding	Simultaneous application in broadcasting and communication ⇒Difficult to implement	Applicable at different times in broadcasting and communication ⇒Easy to implement
Subcarrier spacing	Same for broadcasting and communication	Variable for broadcasting and communication

II. Adaptive Radio Control for IPTV and Data Communication

Variable Subcarrier Spacing

Regarding the SCS of Orthogonal Frequency Division Multiplexing (OFDM), while 15 kHz is specified by 3GPP for 4G LTE, two wider SCS options of 30 kHz and 60 kHz are specified for the sub 6 GHz band (100 MHz bandwidth) of private 5G. The OFDM symbol length of 30 kHz is twice that of 60 kHz. A comparison of them is shown in Table 3. The advantages of 60 kHz include less interference between subcarriers and less transmission delay for occasional communication data due to the shorter symbol length. However, since the Synchronization Signals Block (SSB) is undefined in a radio resource block for 60kHz, some other synchronization means such as GPS may be required. On the other hand, 30 kHz has the advantage of being less affected by multipath fading due to the longer guard interval. Additionally, since SSB is defined, it can complement the synchronization of 60 kHz.

Table 3: Comparison of 30kHz and 60kHz

Subcarrier spacing	Advantages	Disadvantages
30kHz	• Less susceptible to fading • SSB is defined	• Subcarrier spacing interference increases • Increased transmission delay
60kHz	• Reducing inter-subcarrier interference • Transmission delay halved	• Susceptible to fading • SSB is undefined

Based on the above results, considering the low latency of communication data and the fading resistance of IPTV, it is inferred that a variable SCS of 60 kHz is effective for communication, while 30 kHz is more suitable for IPTV.

Dynamic TDD Configuration

Regarding the TDD configuration that allocates UL and DL to each slot in units of 5ms (10 slots for 30 kHz and 20 slots for 60 kHz), in private 5G, a semi-synchronous pattern with increased UL is used, similar to the synchronization pattern of major mobile communication carriers. On the other hand, 3GPP also defines a configuration called dynamic TDD, which allows the allocation of UL and DL slots to be dynamically changed according to UL/DL traffic conditions. By prioritizing DL for IPTV multicast and adaptively allocating UL/DL slots for communication data including unicast, based on demand, this method can minimize the waste of unused slots.

Figure 3 shows each TDD pattern, considering variable SCS for synchronous, semi-synchronous, and dynamic configurations.

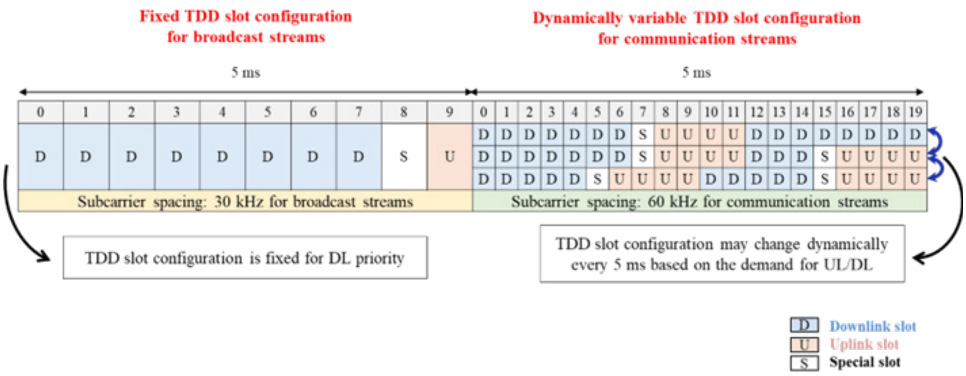

Figure 3: TDD Configurations

The UL/DL slot pattern of dynamic TDD is described in DL Control Information (DCI) format 2_0.

FWA Specialized Radio Control/Parameter Extraction

While various radio control functions related to mobile communication are specified in 5G, such functions are unnecessary for Fixed Wireless Access (FWA), which can reduce the implementation burden on the system. Table 4 lists the main radio control functions that are unnecessary for FWA in both Base Station (BS) and UE.

Table 4: Radio Control of Functions Unnecessary for FWA

Unnecessary radio control functions of BS	Contents
Handover	Function that allows seamless switching between different BS while the UE is moving.
Mobility Management	Function that tracks the location information of the UE and connects it to the optimal BS.
Inter-cell Interference Management	Function that manages interference between multiple BS.
Roaming	Function that maintains connection between different networks.
Cell Resize	Function that dynamically adjusts the size of cells.
Cell Reselection	Function that allows the terminal to select the optimal cell.
Cell ID Management	Function that manages the identifiers of cells.
Dual Connectivity(DC)	Function that allows the terminal to connect to multiple BS simultaneously (usually 4G LTE eNB and 5G NR gNB).
DRX(Discontinuous Reception)	Function to reduce the power consumption of mobile devices

Unnecessary radio Control Functions of UE	Contents
Location Registration	Function that allows the UE to transmit its location information to the BS.
Location Update	Function that updates the location information of the UE to the BS as it changes in mobile communication.

In the BS, 9 functions from handover to Discontinuous Reception (DRX) are unnecessary, and in the UE, 2 functions related to location registration and updating are unnecessary, which is expected to simplify radio control. On the other hand, the traffic of radio control parameters related to these functions in the BS is estimated to be about 100 kbit/s in total, as shown in Table 5. Although lower-order QAM modulation is applied to them, the proportion of transmission capacity they occupy is extremely small, and thus, the effect from the perspective of information volume reduction is not expected to be significant.

Table 5: The Traffics of Radio Control Parameters for FWA Specialization

Unnecessary Wireless Control Functions of BS	Parameter (Partial)	Occurrence Frequency ※ (Assumed Conditions)	Traffic/s
Handover	Measurement Report etc.	0.001 Times/s	100bit
Mobility Management	Tracking Area Update etc.	0.01 Times/s	1kbit
Inter-cell Interference Management	Interference Coordination etc.	0.001 Times/s	100bit
Roaming	Authentication etc.	0.001 Times/s	100bit
Cell Resize	Cell Range Expansion etc.	0.001 Times/s	100bit
Cell Reselection	Neighbor Cell List etc.	0.001 Times/s	100bit
Cell ID Management	Physical Cell ID etc.	0.001 Times/s	100bit
Dual Connectivity(DC)	Secondary Cell Group etc.	0.001 Times/s	100bit
DRX(Discontinuous Reception)	DRX Cycle etc.	10 Times/s	100kbit
Total			**101.7kbit**

III. Concept of Multi-Program Multicast

In cable multi-programs TV broadcasting (multicast), assuming high-quality transmission using the latest video compression technology, Versatile Video Coding (VVC), it is expected that 4K video will require about 10-15 Mbps, HD will require about 5-10 Mbps, and SD will require about 3-5 Mbps. When applying multi-carrier OFDM in a 100 MHz bandwidth, the effective transmission throughput for both UL and DL is approximately 400 Mbps for SISO and about 1 Gbps for 4×4 MIMO. This capacity is not sufficient for providing dozens of Cable TV programs by IP multicast over 5G, necessitating efficient allocation of resource blocks for other internet data. Particularly in multicast, the common MCS needs to be set lower to accommodate UE in poor reception environments, making the required number of resource block more susceptible to reception conditions.

The following measures can be considered:
1. Maintaining higher-order MCS for IP multicast through adaptive MBS combined with unicast.
2. Expanding of resource block for internet data through multi-stream MIMO.
3. Fixing the number of resource blocks through the application of scalable video coding that adapts to MCS variations.

It is necessary to consider the two other approaches, aside from the main task above point 1, from both the perspectives of system implementation and service quality.

Based on the variable SCS and dynamic TDD discussed in Chapter 2, Figure 4 and 5 respectively show conceptual diagrams and examples of radio frame configurations for the broadcast quality assurance type and broadcast quality variable type as approaches for the points 2 and 3.

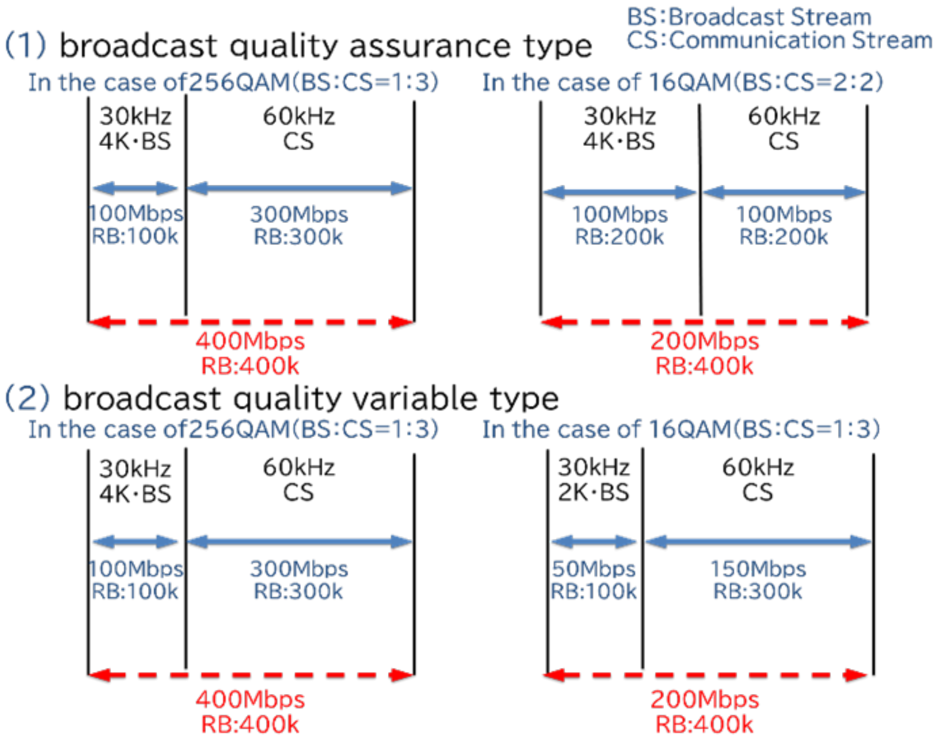

Figure 4: Concepts of Broadcast Quality Guarantee type and Variable type

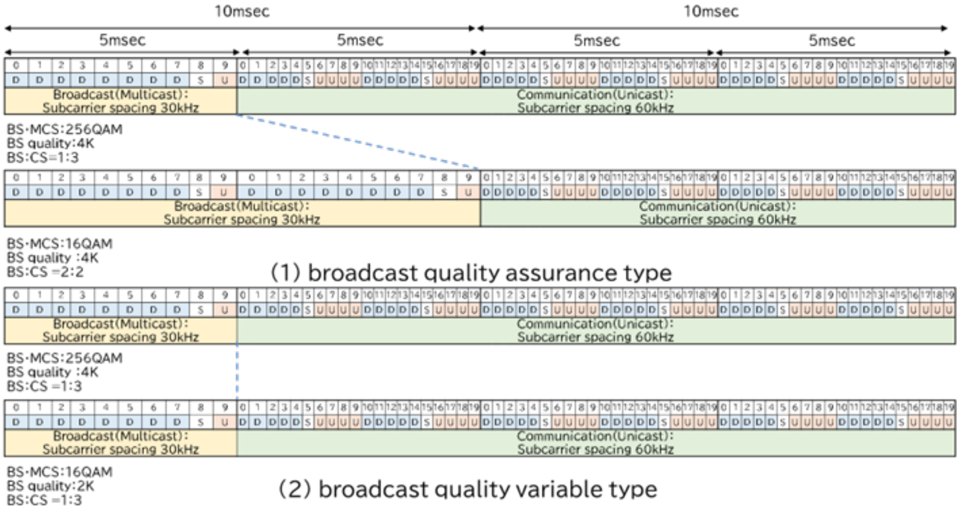

Figure 5: Example of Multicast Radio Frame Configuration

IV. Simulation Analysis

Configuration of MIMO Simulator

A simulator has been developed to model a cable TV IP broadcasting system utilizing MIMO for private 5G, with a focus on multi-dwelling reception. The simulator incorporates multi-dwelling house models, broadcasting models, and viewing models as input parameters to a conventional radio propagation simulator, while also considering MIMO parameters for enhancing transmission quality and speed. Figure 6 presents the overall configuration diagram.

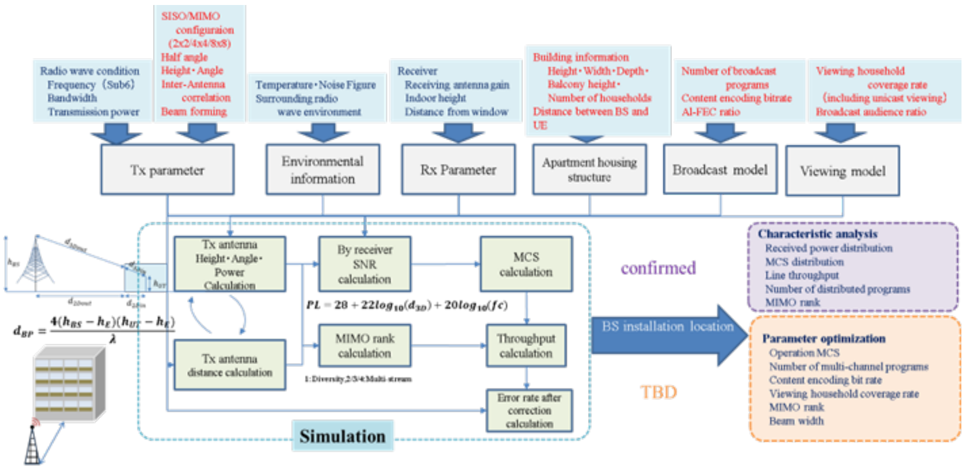

Figure 6: Configuration of MIMO Radio Propagation Simulator for IP Broadcasting to Multi-Dwelling

The left portion of the diagram defines the one-to-one positional relationship between the transmitting base station and the housing complex as a parameter. The household structure within the complex is also defined as an input parameter, enabling the simulation of reception characteristics for each individual household.

This attenuation of radio waves as they penetrate from outdoors to indoors, known as O2I (Outdoor to Indoor) penetration loss, is modeled according to the methodology described in reference [6]. Simulations assume a distance of 100 m to 1 km between the base station and the housing complex, with the FWA line in a Line Of Sight (LOS) environment. Considering the propagation loss at breakpoints in the LOS environment and the height of the base station antenna, we adopted the Urban Macro (UMa) model as the basic propagation loss calculation formula.

The upper part of the figure shows various configurable parameters from the transmitting antenna to the viewer model. These allow characteristic analysis and parameter optimization under each setting condition. The input parameters of the simulator encompass both SISO and MIMO configurations for the transmitting antennas. For MIMO, which is expected to provide a diversity effect on the IP multicast stream, the parameters can be adjusted to reflect the number of antennas, the correlation between MIMO propagation paths, and the implementation of beamforming. The structural parameters of the housing complex include building height, width, balcony height, number of households, and the distance between the base station and each household. The broadcasting model incorporates parameters such as the number of IP multicast programs and content coding bit rate.

The viewing model allows for time-varying settings of viewing household and the viewing rates. The simulator outputs include received power distribution, MCS distribution, transmission throughput, BLER distribution, MIMO rank distribution, and the number of IP multicast programs for each household in the complex.

Theoretical Analysis of Adaptive MBS over Hybrid MIMO

For the three methods of unicast, multicast, and adaptive MBS, the analytical formulas for each method were examined for characterization based on the aforementioned MCS distribution on SISO and MIMO. Two evaluation indices, the number of resource blocks remaining from the resource blocks consumed in program delivery and the remaining transmission capacity, were taken up. These analytical formulas are shown below (1) - (6). Here, the maximum MCS index is 27, based on MCS table defined by 3GPP.

(1) SISO-unicast

・remaining resource block：

$$RRu = Rb - B \cdot \sum_{i=1}^{27} \frac{Utcpvi}{TPri}$$

・remaining transmission capacity：

$$RTu = PRu \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

(2) SISO-multicast

・remaining resource block：

$$RRm = Rb - \frac{L \cdot B}{TPr(min)}$$

・remaining transmission capacity：

$$RTm = RRm \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

(3) SISO-adaptive MBS

・remaining resource block：

$$RR = Rb - \left(\frac{Lk \cdot B}{TPr(k)} + B \cdot \sum_{i=1}^{k-1} \frac{Utcpvi}{TPri}\right)$$

・remaining transmission capacity：

$$RT = PR \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

(4) MIMO-unicast

・remaining resource block：

$$RRu = m \cdot Rb - B \cdot \sum_{i=1}^{27} \frac{Utcpvi}{TPri}$$

・remaining transmission capacity：

$$RTu = RRu \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

(5) MIMO-multicast

・remaining resource block：

$$RRm = m \cdot \frac{L \cdot B}{TPr(min)}$$

・remaining transmission capacity：

$$RTm = RRm \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

(6) MIMO-adaptive MBS

・remaining resource block：

$$RR = Rb \cdot m - \left(m \cdot \frac{Lk \cdot B}{TPr(k)} + B \cdot \sum_{i=1}^{k-1} \frac{Utcpvi}{TPri} \right)$$

・remaining transmission capacity：

$$RT = RR \cdot \sum_{i=1}^{27} \frac{TPri \cdot Utcpwi}{N - n}$$

Symbol definition is below.

TPi	Total throughput when *MCSi* is applied to all resource blocks
TPri	Throughput per resource block for *MCSi, TPri = TPi/Rb*
TPr (min)	Throughput per resource block at minimum *MCS, TPr (min) = TP (min)/Rb*
Rb	Total number of resource blocks
B	Program bitrate
N	Total number of households
n	Number of viewing households
L	Total Number of programs
m	Number of MIMO layers
k	*MCS* value for multicast-unicast separation setting in MBS
Lk	Number of programs for multicast viewing households at *MCS (i = k)*
Utcpvi	Number of receiving viewing households for *MCSi* based on unicast viewing distribution, $\sum_{i=1}^{27} Utcpvi = n$
Utcpwi	Number of receiving non-viewing households for MCSi based on unicast viewing distribution, $\sum_{i=1}^{27} Utcpwi = N - n$

Results

Distribution Characteristics of MCS in Housing Complexes

The characteristics of the MCS distribution for MIMO transmission to a 100-household apartment complex, with a distance between the BS and UE of 100 meters and a transmission power of 1W, are shown in Figures 7 and 8, along with SISO results. Figures 7 and 8 show the simulation results for the IP multicast (broadcast) at diversity MIMO and the IP unicast (communication) at multi-stream MIMO, respectively.

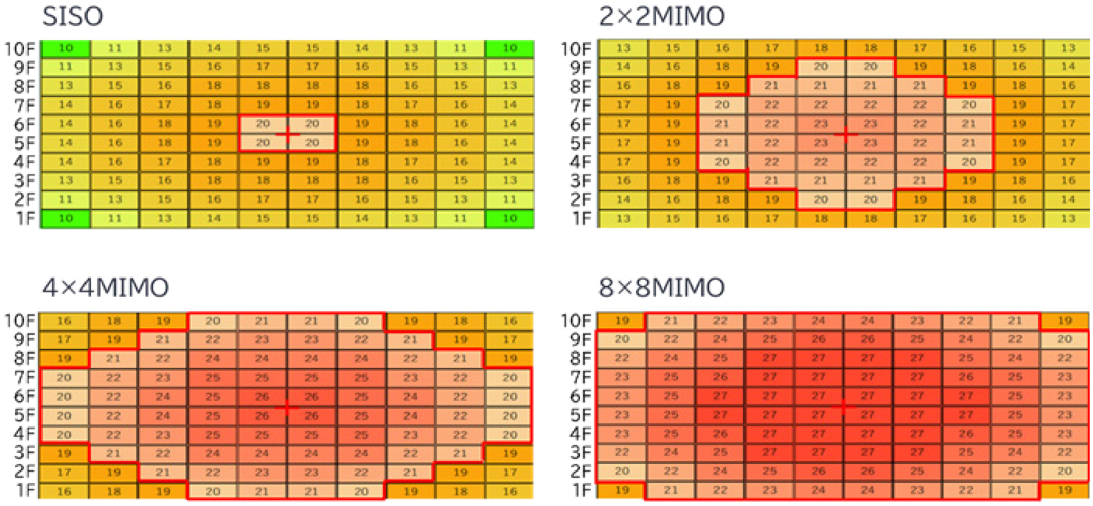

Figure 7: MCS Distribution for IP Multicast by UDP

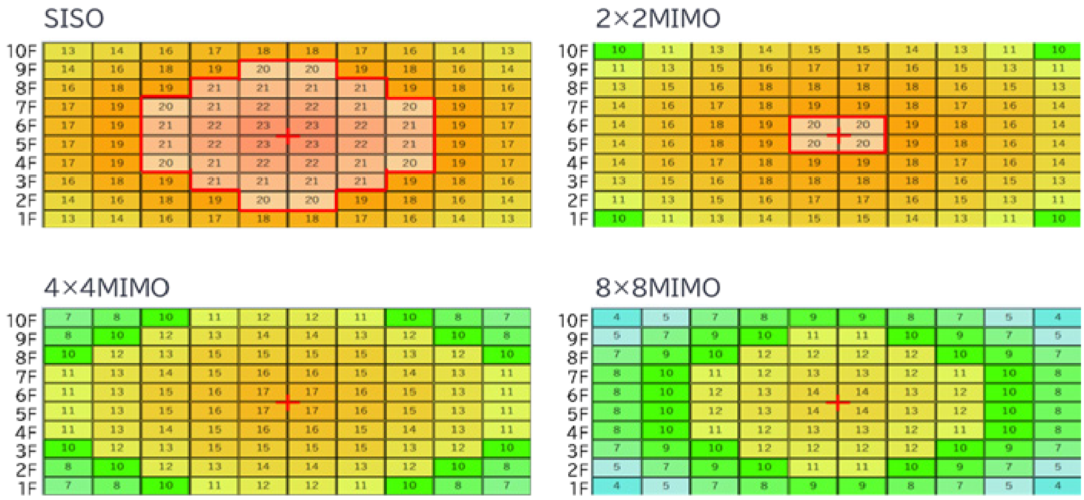

Figure 8: MCS Distribution for IP Unicast by TCP

When comparing the MCS distribution, about three-step difference is observed. For example, when comparing households receiving 256QAM, in the case of SISO, the IP multicast reaches 4 households, whereas the IP unicast reaches 40 households, significantly improving modulation efficiency. This is due to the retransmission of TCP packets for unicast stream, resulting in an effective SNR improvement.

In the case of MIMO, assuming a 100% MIMO gain, the diversity effect on the IP multicast stream results in an SNR increase of approximately 3dB, 6dB, and 9dB, respectively. Consequently, the minimum MCS increases from 10 in SISO by 3, 6, and 9, respectively, indicating a significant improvement in coding efficiency due to MIMO. Additionally, the number of households adapting to 256QAM increases from 4 households (SISO) to 40 (2×2MIMO), 76 (4×4MIMO), and 96 (8×8MIMO) households, respectively, confirming the MIMO effect on the multicast stream.

On the other hand, for unicast using multi-stream MIMO, the characteristics of the MCS distribution decrease as the number of MIMO layers increases due to the reduction in received power caused by the loss of transmit power splitting, and for example, the MCS drops by 9 levels compared to 4×4 diversity MIMO. However, the total resource block increases by a factor of 4, and the reduction in coding efficiency is compensated by the expansion of the resource block.

Simulation Analysis

Table 6 shows the parameters set for the simulation. The transmit power, distance between base stations and terminals, and total number of households in the apartment complex correspond to those used in previous field tests conducted by the authors and others. The coding bit rate assumes 4K-VCC. For broadcast/multicast, diversity MIMO prioritizing reliability is assumed; for communication/unicast, multi-stream MIMO prioritizing transmission efficiency is assumed; and for adaptive MBS, hybrid MIMO combining both is assumed. The antenna half-power beamwidth was set to 30° to ensure the received power for all apartment households remained within approximately 3dB, and to 15° (half of 30°) as an example of a partially degraded reception environment.

Table 6: Simulation Parameters

Parameter	Value
Transmission power	1W
Distance between BS and UE	100m
Number of households	10-story building with 100 households
Content encoding bitrate	10Mbps
Number of broadcast programs	10 programs
SISO/MIMO configuration	SISO, 4×4MIMO
Viewing household coverage rate	10, 20, …, 90%
Half Angle (horizontal, vertical)	15°, 30°

To evaluate frequency utilization efficiency metrics, we also assessed the characteristics when applying diversity MIMO during multicast to remaining resource blocks. Therefore, in addition to consumed resource blocks, we defined the number of remaining resource blocks. For communication/unicast and adaptive MBS, we assumed multi-stream MIMO application for remaining resource blocks. For broadcast/multicast, we treated remaining resource blocks as either single or MIMO layer-multiplied. We adopted this approach for evaluation and analysis.

Figure 9 and 10 show the differences in the characteristics of each remaining resource block when the antenna half-power beamwidth is set to 30° and 15°, respectively.

The red line represents RR-RRm, the blue line RR-RRu, the solid line SISO, and the dashed line 4×4 MIMO. Higher values on the vertical axis indicate greater advantage of adaptive MBS over multicast and unicast. The bar graphs in the figure represent multicast delivery, unicast delivery, and combined multicast and unicast delivery, showing the delivery method with the highest link efficiency for each number of viewing households.

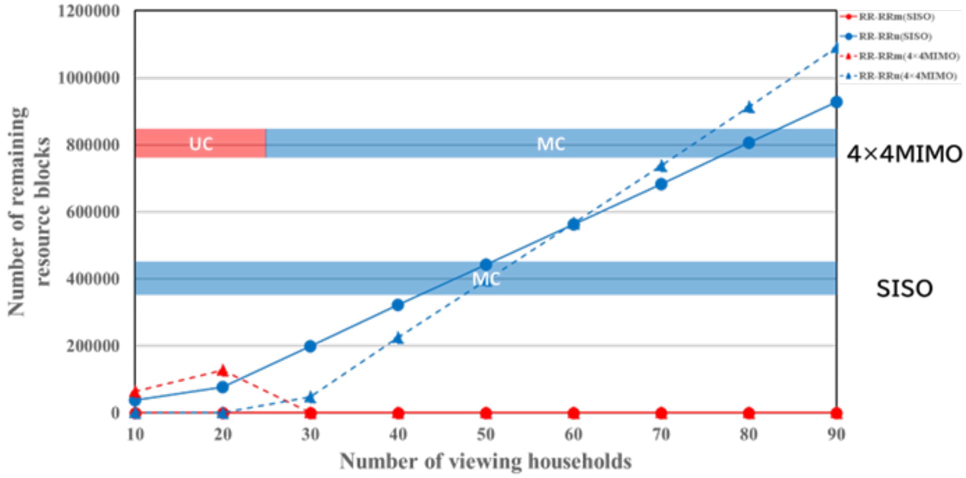

Figure 9: Remaining Resource Block at Half-Power Beamwidth of 30°

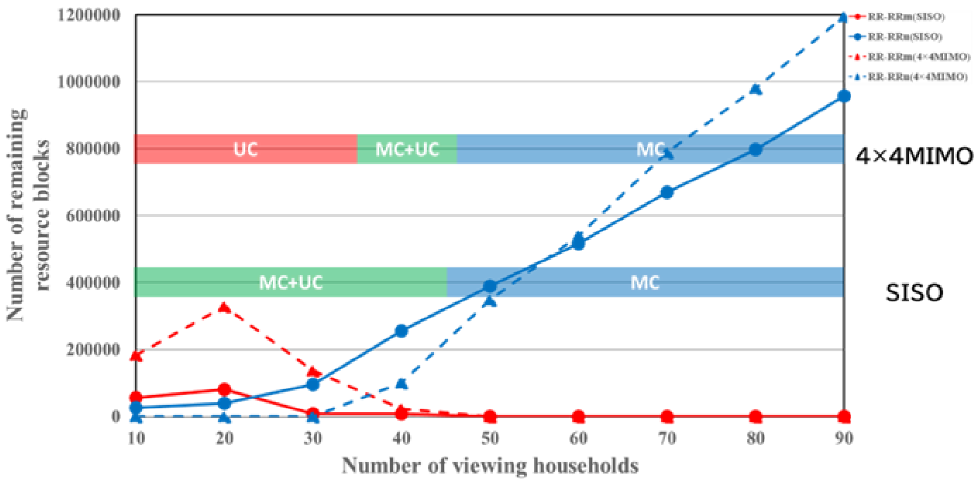

Figure 10: Remaining Resource Block at half-Power Beamwidth of 15°

We examined cases where radio wave interference occurred in some households due to obstructions such as nearby buildings and trees. For comparison with Figure 9, simulations were conducted under the conditions specified in Table 6, setting the antenna half-power beamwidth to 30°. Figure 11 shows the residual resource block characteristics when considering a 3dB radio wave attenuation for households on the first floor of apartment buildings.

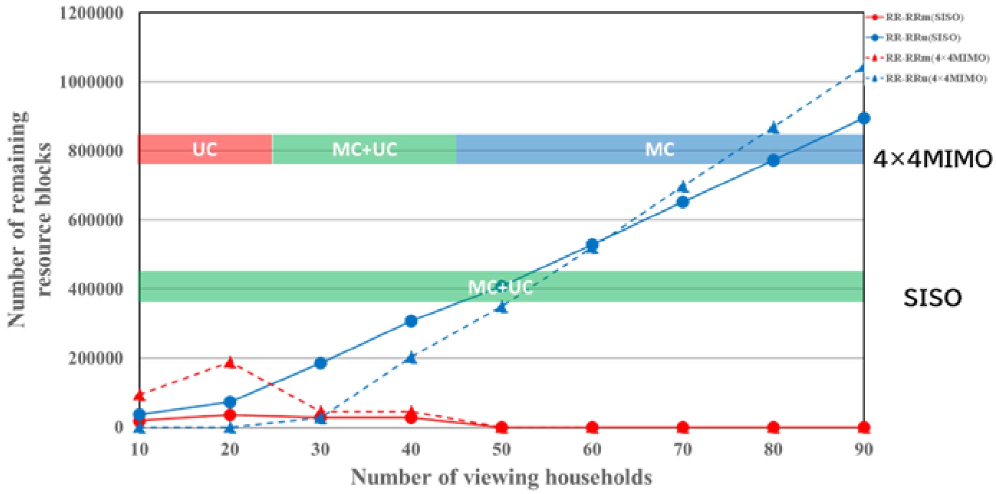

Figure 11: Remaining Resource Block at Radio Interference

Discussion

Distribution Characteristics of MCS in housing complexes

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Simulation Analysis

At a half-power beamwidth of 30°, adaptive MBS was confirmed to be particularly advantageous over multicast as the number of viewing households increased. For SISO, multicast transmission was advantageous at any number of viewing households. Conversely, for 4×4 MIMO, with 10 to 20 viewing households, unicast transmission was found to be suitable because the number of resource blocks increases proportionally to the number of layers due to multi-stream MIMO. Conversely, for viewer households between 30 and 90, multicast delivery via diversity MIMO became dominant, and no advantage for combined delivery was confirmed.

Next, at a half-power beamwidth of 15°, compared to 30°, adaptive MBS was found to be even more advantageous than multicast and unicast. For SISO, combined transmission was confirmed to be advantageous for viewer households between 10 and 40, and for 4×4 MIMO, it was advantageous for 40 households. This advantage stems from narrowing the half-power beamwidth, which improves received power and SNR for households within the beamwidth. This enables the use of higher-order MCS, thereby reducing the number of resource blocks required for viewing. Conversely, for households outside the half-power beamwidth, multicast transmission cannot meet the common MCS required, making unicast transmission—which applies the optimal MCS per household—relatively advantageous. Consequently, the disparity in transmission conditions between inside and outside the half-power beamwidth widened, making the superiority of combined transmission apparent.

When radio interference occurs, it was confirmed that co-delivery is advantageous for any viewing household in SISO. This is because, in adaptive MBS co-delivery, unicast can be applied to households where the reception environment deteriorates and results in a lower MCS, while a higher common MCS can be set for multicast delivery target households, thereby reducing the number of resource blocks used.

For 4×4 MIMO, when the number of viewing households was 10 to 20, unicast delivery via multi-stream MIMO was advantageous because it could apply a higher MCS to each household. When the number of viewing households was 50 to 90, Multicast delivery via diversity MIMO became advantageous because it improved the common MCS by several levels. When the number of viewing households was 30 to 40, the advantage of hybrid MIMO-based combined delivery was confirmed.

Conclusion

We considered radio control scheme for cable TV IPTV using private 5G under adaptive MBS, featuring hybrid MIMO, TDM multiplexing, variable SCS, and dynamic TDD. In the case of IPTV FWA, the variation in the radio environment of receiving households is minimal, resulting in little fluctuation in MCS. Therefore, it is considered feasible to fix the IP broadcasting resource block even in the broadcast quality assurance type.

Simulation experiments were conducted to quantitatively clarify the MIMO effect from the MCS distribution in the housing complex, and to quantitatively analyze the effectiveness of the adaptive MBS, we examined the characteristic analysis equation, together with unicast and multicast. Detailed analysis will be conducted in the future. In addition, we are currently developing an emulator consisting of a video distribution serve resource block, virtual MIMO space, and UE to conduct performance verification and implementation studies. Future issues include the study of the implementation aspects of the proposed method for commercialization.

Using a simulator, we analyzed the comparative characteristics of adaptive MBS, multicast, and unicast from the perspective of remaining resource blocks.

The results indicate that during MIMO transmission under favorable reception conditions, the effect of combining multicast and unicast —a characteristic of adaptive MBS—is not significant, though it depends on the number of difficult-to-broadcast groups and the number of viewing households. Conversely, when differences in reception power occur between viewing households due to factors like narrow half-power beamwidth or radio wave interference, the combined multicast and unicast delivery effect is confirmed to become significantly stronger.

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Conflicts of Interest

Authors state no conflict of interest.

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