Development of 38GHz-band wireless communication system using high altitude platform station (HAPS) for 5G network - study on effective frequency resources utilization with polarization -

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Abstract: HAPS (High-Altitude Platform Station) is expected to extend the communication coverage in the era of beyond 5G. HAPS moves around a circle at 20 km altitude and tries to make beams fixed on the earth by beamforming. However, if HAPS uses polarization like satellite communication, there is a possibility that received SNR (Signal to Noise power Ratio) degrades because the fluctuation of HAPS aircraft could generate polarization mismatch between HAPS and earth stations. This paper reports experimental results using on-air polarization signal from a satellite with artificial polarization offset to evaluate feasibility of polarization utilization in HAPS. The results show SNR loss due to the polarization offset can be confined within 0.5dB and good tracking performance thanks to the polarization diversity by MMSE (Minimum Mean Square Error) receiver.

Keywords: HAPS, polarization, diversity, MMSE

Classification: Satellite communications

References

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[2] “ETSI TR 102 376-2: Digital Video Broadcasting (DVB) Implementation guidelines for the second generation system for Broadcasting, Interactive
1 Introduction

HAPS (High-Altitude Platform Station) is expected to extend the communication coverage in the era of beyond 5G. It is also expected that HAPS system will realize broadband backhaul communication link for 5G in 38 GHz-band [1], because it is allocated to HAPS in WRC-19 (World Radiocommunication Conferences 2019). Polarization is used in satellite communication for effective frequency resources utilization. Frequency reuse 4 is a typical example [2], in which one combination from two frequencies and two polarizations is allocated to each beam. HAPS moves around a circle at 20 km altitude and tries to make beams fixed on the earth by beamforming. However, if HAPS uses polarization like satellite communication, there is a possibility that received SNR (Signal to Noise power Ratio) degrades because the fluctuation of HAPS aircraft could generate polarization mismatch between HAPS and earth stations. This paper reports experimental results to evaluate feasibility of polarization utilization in HAPS.

2 Experimental method to evaluate feasibility of polarization utilization in HAPS

In order to evaluate the feasibility of polarization utilization for HAPS, experimental measurement was conducted using polarization signal from the existing satellite. Fig. 1 shows the experimental method and structure. Because current satellite communication uses DVB-S2 standard [3], as shown in Fig. 1, we developed a MMSE (Minimum Mean Square Error) receiver using orthogonal polarizations (i.e. vertical and horizontal) and evaluated received SNR of DVB-S2 on-air signal (either one of orthogonal polarizations) in Ku-band (12 – 18 GHz) from a stationary satellite (GEO: Geostationary Orbit) at about 36,000 km altitude. Artificial polarization offset was given to the earth station in this experiment to emulate polarization mismatch between HAPS and earth stations due to the fluctuation of HAPS aircraft.

Services, News Gathering and other broadband satellite applications; Part 2: S2 Extensions (DVB-S2X),” November, 2015.

ETS1 EN 302 307-1: Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part 1: DVB-S2,” November, 2014.

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Fig. 1. Experimental method and structure to evaluate feasibility of polarization utilization in HAPS

3 MMSE algorithm

This section explains MMSE algorithm. Here the following symbols are defined.

- \( r(t) \): Received signal \( (= [r_V(t) \ r_H(t)]^T) \)
- \( d(t) \): Desired signal
- \( u(t) \): Undesired signal, i.e. interference
- \( n(t) \): Thermal noise \( (= [n_V(t) \ n_H(t)]^T) \)

- \( H \): Channel matrix \( (= [h_d \ h_u]^T) \)

\( h_d \): Channel response of desired signal \( (= [h_{VV} \ h_{HV}]) \)

\( h_u \): Channel response of undesired signal \( (= [h_{VH} \ h_{HH}]) \)

Then the received signal \( r(t) \) is expressed as follows.

\[
r(t) = h_d d(t) + h_u u(t) + n(t)
\]  

(1)

MMSE algorithm is a method to minimize noise plus interference power. When undesired signal \( u(t) \) and the channel response \( h_u \) are unknown, the estimated desired signal \( \hat{d}(t) \) is expressed as follows.

\[
\hat{d}(t) = w^H r(t)
\]  

(2)

\[
w = h_d (E[r(t)r^H(t)])^{-1}
\]  

(3)

Cross-correlation between received signal \( r(t) \) and the known symbols \( s(t) \) are calculated to estimate \( h_d \) in equation (3), and auto-correlation of received signal \( r(t) \) during the period are calculated to estimate \( E[r(t)r^H(t)] \) as follows.

\[
\bar{h}_d = \frac{1}{L} \sum_{l=0}^{L-1} s(t)^H r(t)
\]  

(4)

\[
E[r(t)r^H(t)] = \frac{1}{L} \sum_{l=0}^{L-1} r(t)^H r(t)
\]  

(5)

The known symbols \( s(t) \) is explained in Appendix.

4 MMSE receiver

Fig. 2 shows the block diagram of MMSE baseband signal processing in the MMSE receiver used for the evaluation.
Fig. 2. Block diagram of MMSE baseband signal processing

4.1 MMSE core
MMSE coeff. module performs MMSE weight calculation described in equation (3), (4) and (5). MMSE weighing module performs MMSE weight multiplication to Roll-off filtered signal based on the equation (2). If “MMSE: on” is set, this module applies MMSE algorithm to Roll-off filtered signal in both of orthogonal polarizations. If “MMSE: off” is set, this module outputs Roll-off filtered signal in either one of orthogonal polarizations.

4.2 Synchronization part
Synchronization part other than MMSE core is explained in this section. Though this part was basically designed based on Annex C in [4], some techniques were implemented for diversity reception as follows.
AGC (Automatic Gain Control) module performs to adjust the level of the incoming signals to the reference level. The signal level is measured as the average of the sum of the powers of both polarizations. The gain control may be performed independently for both polarizations without summing the powers.
AFC (Automatic Frequency Control) module performs to recover the carrier frequency. Because there is a possibility that the signal does not exist in one of orthogonal polarization, the carrier frequencies of both polarizations are controlled by common NCO (Numerical Controlled Oscillator).
Clock recovery module performs to recover the two times of symbol clock from the master clock based on Gardner’s algorithm [5] and to resample the incoming signals on the symbol timing in each polarization. This algorithm is non-data aided and therefore can be run without any frame synchronization. The symbol timing should be same in both polarizations. Roll-off Filter module performs to filter the received signal based on the square root raised cosine characteristics.
Frame Sync module performs to establish frame synchronization. In the initial state (UNLOCK), this module determines the frame start by SOF (Start of Frame) detection in which correlation using the differentially decoded symbols is conducted. When PLS (Physical Layer Signalling) decoding level by maximum likelihood decoding is higher than the predetermined threshold (TPT), this module transitions to the synchronization protection state (LOCKED). In "LOCKED", this
module recovers the frame sequences according to the frame length signaled via PLSCODE. When PLS decoding level is lower than the predetermined threshold (TPL), this module transitions to "UNLOCKED".

5 Experimental result

Fig. 3 (a) and (b) show the experimental result for the case of static and dynamic polarization offset respectively. The horizontal and vertical axes show static polarization offset and received SNR respectively in Fig. 3 (a). It is found that “MMSE: on” keeps stable received SNR within 0.5dB loss, while “MMSE: off” has worse received SNR with more polarization offset. This result shows that diversity reception using MMSE can be expected to absorb polarization offset and keep stable received SNR even for the case of large polarization offset between HAPS and earth stations.

Next, the horizontal and vertical axes show relative time (total time is about 50 minutes) and received SNR respectively in Fig. 3 (b). The average and standard deviation of the dynamic polarization offset is 12.7 and 9.2 degree respectively, and the offset with more than 10 degree was given over 50% of the period. It is found that “MMSE: on” has always higher received SNR than “MMSE: off”. “MMSE: on” keeps stable received SNR even when “MMSE: off” loses synchronization. This result shows that diversity reception using MMSE can be expected to track dynamic polarization offset and keep stable received SNR even for the case of dynamic polarization offset between HAPS and earth stations.

(a) For static polarization offset

(b) For dynamic polarization offset

Fig. 3. Experimental result

The following is the explanation on the applicability of this experimental result to HAPS. Received SNR is roughly expressed by link budget calculation as follows.

\[
\text{SNR [dB]} = \text{EIRP} - \text{Lp} + \frac{G}{T} - k - 10 \log_{10}(B) \quad (6)
\]

where EIRP, Lp, G/T, k and B are equivalent isotropically radiated power [dBW], free space path loss[dB], antenna gain to noise temperature ratio [dB], Boltzmann’s constant (= -228.6) [dB/Hz] and bandwidth [Hz] respectively. A typical link budget calculation on GEO satellite communication using Ku-band and DVB-S2X [2, Table 28] shows EIRP, Lp, G/T and B is 53.5, 205.6, 12.1 and 3.6e7 respectively, and received SNR is calculated as 13.0 dB from (6). The reason of lower received SNR in this experiment (less than 10 dB) could be co-channel
interference from adjacent satellite and so on. On the other hand, a typical link budget calculation on HAPS communication using 38 GHz-band [6, Table I] shows EIRP, Lp, G/T and B is 50.0, 158.2, 10.0 and 8.0e7 respectively, and received SNR is calculated as 21.4 dB from (6). This experiment shows that SNR loss due to the polarization offset can be confined within 0.5dB thanks to MMSE algorithm, and this link budget analysis shows that the received SNR in HAPS communication is better than that in GEO satellite communication. Therefore, it can be considered that MMSE algorithm enables comparable or more precise tracking to polarization offset in HAPS communication and polarization utilization in HAPS communication is feasible.

6 Conclusion
This paper reports experimental results using on-air polarization signal from a satellite with artificial polarization offset to evaluate feasibility of polarization utilization in HAPS. The results show SNR loss due to the polarization offset can be confined within 0.5dB and good tracking performance thanks to the polarization diversity by MMSE receiver.

Acknowledgments
This research is supported by the Ministry of Internal Affairs and Communications in Japan (JPJ000254).

7 Appendix
7.1 Known symbols $s(t)$ in MMSE algorithm
The following is the explanation on the known symbols $s(t)$ in MMSE algorithm. Each frame of DVB-S2 is composed of PLHEADER (1 slot) followed by payload (S slots), where payload has one LDPC (Low Density Parity Check) block (64800 or 16200 bit) and one slot is composed of 90 symbols. Each frame may have pilot symbols, whose 36 symbols are inserted every 16 slots payload. PLHEADER is composed of SOF (26 symbols) and PLSCODE (64 symbols), where SOF is composed of known $\pi/2$ BPSK (Binary Phase Shift keying) symbols ($I_{2i-1} = Q_{2i-1} = (\frac{1}{\sqrt{2}})(1 - 2y_{2i-1})$, $I_{2i} = -Q_{2i} = -(\frac{1}{\sqrt{2}})(1 - 2y_{2i})$, $(y_1, y_2, \ldots, y_{26}) = 18D2E82_{\text{HEX}}, i = 1, 2, \ldots, 26$) and PLSCODE is composed of unknown $\pi/2$ BPSK symbols to notify MODCOD (Modulation order and code rate), LDPC length and “pilot: on/off”. Pilot symbols are composed of un-modulated $\pi/2$ BPSK symbols (known as $I = Q = \frac{1}{\sqrt{2}}$) and randomized by known scrambling sequences. Therefore, $L = 26$ and 36 are respectively for SOF and pilot symbols in equations (4) and (5).