



A New Gateway Switching Strategy in Q/V Band High Throughput Satellite Communication Systems Feeder Links

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Abstract. A main obstacle to limit the capacity of next generation Terabit/s broadband satellite communication is the limited spectrum available in the Ka band. A feasible solution is to move the feeder link to the higher Q/V band, where spectrum is more available. However, the Q/V band is sensitive to rainfall attenuation. Compensating for the falling caused by rainfall, gateway diversity is considered to ensure the required feeder link availability. So far, many strategies for gateway diversity have been proposed, and each of them has its own advantages, so it is imperative to research gateway switching strategies. In this paper, a modified switch and stay combining strategy named TH-SSC is proposed for a Q/V band feeder link, which is suitable for three gateways to switch and we make an analysis and simulations about its performance. It can be seen that this modified TH-SSC strategy is pragmatic and has better performance in some aspects.

Keywords: Gateway diversity · Q/V band · Rain attenuation · Outage probability

1 Introduction

High-throughput satellite (HTS) systems are receiving increasing attention due to the tremendous demand for interactive services. At present, satellite communication systems would provide hundreds of Gigabit services and it is estimated that next generation satellites will require capacity of one Terabit/s (1000 Gbps) by 2020 [1]. A main obstacle for satellite to achieve Terabit/s is the limited spectrum of about 2 GHz available in the Ka band. An expected way is to move the feeder link to the higher Q/V band, where larger bandwidths, up to 5 GHz, are available [2], which not only promotes future system to achieve higher throughput, but also frees up the whole Ka-band spectrum for the user link. However, due to heavy rain attenuation, moving the feeder link to Q/V band imposes considerable strain on the link-budget. There are some strategies to compensate for fading, like Power control and adaptive modulation and coding (ACM) techniques, which are not sufficient to make up for high signal degradations up to 15–20 dB. Gateway diversity is considered as a powerful Fade Mitigation Technique (FMT) to ensure the required feeder link availability.

Gateway diversity is a familiar and mature technique with rich literature, Equal Gain Combining (EGC) and Maximum Ratio Combining (MRC) have been studied in [3] towards achieving transmit diversity. However, these two ways both require precise channel phase information and two gateways are active, which demands huge overhead and strict synchronization.

Since no phase information is required and have higher gateway utilization efficiency, Switch and Stay Combining (SSC) and Selection Combining (SC) strategies have been proposed in many literatures [3–5]. In order to get better performance, many scholars have improved on the basis of the above strategies. Based on SSC strategy, [6] proposed several improved strategies which establish a Markov model. In [7], a modified SSC (MSSC) scheme is proposed to reduce the number of gateway handover.

There are still many studies that promote switching strategies from two gateways to multiple gateways [8–10], which provides a better trade-off between outage and switching rate and have better gateway utilization, but we need compare signal information of active gateways and redundant gateways, which increases the complexity compared with SSC strategies.

Based on the SSC strategy, this paper proposes a three-gateway switching strategy named TH-SSC which is more pragmatic in reality. It has better performance in terms of outage probability and frequency of handovers while maintaining lower handover complexity. The utilization of gateway of original SSC strategy is 50%, but now we enhance it closed to 67%.

The remainder of this paper is organized as follows. Section 2 introduces the system model which is used in this paper. Section 3 studies the modified switching strategy and analysis the performance of it. Numerical results are presented in Sect. 4. Concluding remarks are provided in Sect. 5.

2 Research Scenario and System Model

Two active gateways, namely GW_1 and GW_2 , separated by a distance of D_1 , which distances from the backup gateway GW_3 , D_2 , D_3 and communicate with the GEO satellite through a feeder link operating in the Q/V band. The approach is depicted in the Fig. 1

Assume that the active GW transmits the signal $s(t)$ having an average power E_1 and E_2 . The decision on switching is taken at discrete time instants $t = NT$, where N is an integer and T is the interval between switching instants. The channel between GW_i and the satellite at $t = NT$ is denoted by $h_i[n] = |h_i[n]|e^{j\theta_i}$, where $i = 1, 2, 3$ and θ_i is the phase component of GW_i .

The channel amplitude, $|h_i[n]|$, can be estimated using a beacon signal received from the satellite. The clear sky signal-to-noise ratio (SNR) for the feeder uplink is then defined as SNR_{CS} . The actual SNR for the link between GW_i and the satellite at $t = NT$ can be obtained by $SNR_R = |h_i[n]|^2 E/N = |h_i[n]| SNR_{CS}$.

It is well known that the Lognormal distribution is an acceptable model for describing statistical data on rainfall rate, especially in areas with low rainfall rates [11]. Let the rain attenuation at GW_i be A_i , then we can obtain the following formulas (1),

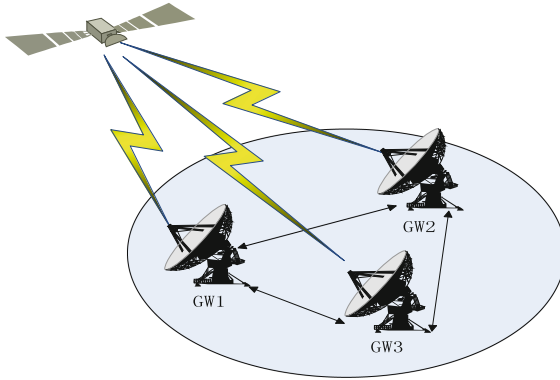


Fig. 1. The strategy of TH-SSC

where $\langle \ln A_i \rangle$ and δ_i are the mean and standard deviation of $\ln A_i$. ρ is the spatial correlation coefficient for two GWs separated by a distance of D km, which can be obtained by formula $\rho_{ij} = 0.94 \exp(-\frac{D}{30}) + 0.06 \exp(-(\frac{D}{500})^2)$.

$$A_i = -10 \log_{10}(|h_i[n]|^2) \quad \alpha_i = \frac{\ln A_i - \langle \ln A_i \rangle}{\delta_i} \tag{1}$$

$$f_{A_i A_j}(A_i, A_j) = \frac{1}{2\pi A_i A_j \sigma_i \sigma_j \sqrt{1 - \rho^2}} \exp\left(-\frac{1}{2(1 - \rho^2)} [\alpha_i^2 - 2\rho_{ij}\alpha_i\alpha_j + \alpha_j^2]\right)$$

We can think if the distance exceeds 100 km, it is basically no longer relevant. Assuming that the uplink signal-to-noise ratio SNR_{CS} is fixed in clear sky, the satellite received signal power is directly related to the rainfall attenuation. According to strategy, gateway switching from active GW_i to redundant GW_j occurs if SNR_R is lower than threshold, which is rainfall attenuation $A_i > \beta_i$, β_i is the threshold of rainfall attenuation.

3 TH-SSC Based Gateway Switching Strategy

3.1 Switching State Analysis

We now study the outage performance of TH-SSC. Assuming the outage threshold of GW_i is β_i , which is the attenuation when outage occurs. The switching rules is as follows.

- (1) When the active gateway is GW_1 and GW_2 at time $t = NT$,
 If $A_1 > \beta_1$ switching between GW_1 and GW_3
 Else if $A_1 < \beta_1$ and $A_2 > \beta_2$, switching between GW_2 and GW_3
- (2) When the active gateway is GW_1 and GW_3 at time $t = NT$,
 If $A_3 > \beta_3$ switching between GW_2 and GW_3
 Else if $A_3 < \beta_3$ and $A_1 > \beta_1$, switching between GW_2 and GW_1

According to the switching rule, when the rain attenuation of the two active gateways is higher than the respective thresholds, there will be a gateway outage; when the rain attenuation of the three active gateways is higher than the respective thresholds, two gateways will be outage. Threshold vary depending on the link attenuation characteristics.

In general, we think that the distance between satellite gateways is several hundred kilometers. So we can approximate that the rainfall attenuation is not related to each other. Assuming the outage threshold of GW_i is β_i , which is equal with switching threshold.

We can use the Markov chain to solve parameters such as outage probability, switching rate, and average gain. First we need to define the nine states in the Markov chain, as shown in Table 1 below.

Table 1. 9 kinds of transmission status of switching

State at $t = N(T - 1)$	Active GWs	Relationship	State at $t = NT$
State 1	GW1, GW2	$A_1 > \beta_1$	GW2, GW3
State 2	GW1, GW2	$A_1 < \beta_1, A_2 > \beta_2$	GW1, GW3
State 3	GW1, GW2	$A_1 < \beta_1, A_2 < \beta_2$	GW1, GW2
State 4	GW1, GW3	$A_3 > \beta_3$	GW1, GW2
State 5	GW1, GW3	$A_3 < \beta_3, A_1 > \beta_1$	GW2, GW3
State 6	GW1, GW3	$A_1 < \beta_1, A_3 < \beta_3$	GW1, GW3
State 7	GW2, GW3	$A_2 > \beta_2$	GW1, GW3
State 8	GW1, GW3	$A_2 < \beta_2, A_3 > \beta_3$	GW1, GW2
State 9	GW1, GW3	$A_2 < \beta_2, A_3 < \beta_3$	GW2, GW3

Define P_i as the probability of GW_i outage, we can obtain formula (2)

$$P_i = \Pr(A_i > \beta_i) = \int_{\beta_i}^{\infty} f_i(A_i) dA_i = \int_{\beta_i}^{\infty} \frac{1}{2\pi A_i \sigma_{\ln A_i}} \exp\left(-\frac{\alpha_i^2}{2}\right) dA_i, i = 1, 2, 3 \quad (2)$$

We can conclude from Table 1 that the next possible state of State 1 is State 7, State 8, and State 9. Since the links are considered to be uncorrelated, it can be concluded that the probability of switching from state 1 to state 7 is P_2 . So we can get the transition matrix M as formula (3).

$$M = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & P_2 & P_3(1-P_2) & (1-P_3)(1-P_2) \\ 0 & 0 & 0 & P_3 & P_1(1-P_3) & (1-P_3)(1-P_1) & 0 & 0 & 0 \\ P_1 & P_2(1-P_1) & (1-P_1)(1-P_2) & 0 & 0 & 0 & 0 & 0 & 0 \\ P_1 & P_2(1-P_1) & (1-P_1)(1-P_2) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P_2 & P_3(1-P_2) & (1-P_3)(1-P_2) \\ 0 & 0 & 0 & P_3 & P_1(1-P_3) & (1-P_3)(1-P_1) & 0 & 0 & 0 \\ 0 & 0 & 0 & P_3 & P_1(1-P_3) & (1-P_3)(1-P_1) & 0 & 0 & 0 \\ P_1 & P_2(1-P_1) & (1-P_1)(1-P_2) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P_2 & P_3(1-P_2) & (1-P_3)(1-P_2) \end{pmatrix} \quad (3)$$

Define π_i as the probability that state i appears, P_{i-j} as the probability that transform from state i to state j . We can obtain formula (4) as follows:

$$\begin{cases} \pi_j = \sum_{i=1}^9 P_{i-j} \times \pi_i \\ \sum_{i=1}^9 \pi_i = 1 \end{cases} \quad (4)$$

Assuming $\vec{\pi} = [\pi_1, \pi_2, \dots, \pi_9]$, then $\vec{\pi} = \vec{\pi}M$, we can get formula (5), where $\Delta = P_1 + P_2 + P_3$, $\lambda = P_1P_2P_3$

$$\vec{\pi} = \left(\frac{P_1P_3}{\Delta}, \frac{P_2P_3 - \lambda}{\Delta}, \frac{P_3 - P_1P_3 - P_2P_3 + \lambda}{\Delta}, \frac{P_2P_3}{\Delta}, \frac{P_1P_2 - \lambda}{\Delta}, \frac{P_2 - P_1P_2 - P_2P_3 + \lambda}{\Delta}, \frac{P_1P_2}{\Delta}, \frac{P_1P_3 - \lambda}{\Delta}, \frac{P_1 - P_1P_2 - P_1P_3 + \lambda}{\Delta} \right) \quad (5)$$

3.2 Outage Probability Analysis

Probability of an outage (SNR below the threshold at two gateways) is (6)

Where $P(i, j) = \Pr(A_i > \beta_i, A_j > \beta_j, A_{another} < \beta_{another})$

$$\begin{aligned} P_{OUT1} &= P(1, 2) + P(1, 3) + P(2, 3) \\ &= (\pi_1 + \pi_2 + \pi_3) \times P_1P_2 + (\pi_4 + \pi_5 + \pi_6) \times P_1P_3 + (\pi_7 + \pi_8 + \pi_9) \times P_2P_3 \end{aligned} \quad (6)$$

Probability of two outages (SNR below the threshold at all gateways) is (7)

$$\begin{aligned} P_{OUT2} &= (\pi_1 + \pi_2 + \pi_3) \times P_1P_2P_3 + (\pi_4 + \pi_5 + \pi_6) \times P_1P_2P_3 + (\pi_7 + \pi_8 + \pi_9) \\ &\quad \times P_1P_2P_3 = P_1P_2P_3 \end{aligned} \quad (7)$$

So the frequency at which the outage occurs is as formula (8)

$$f_{OUT} = \frac{P_{OUT1} + 2P_{OUT2}}{3T} \quad (8)$$

3.3 Switching Frequency Analysis

When the system is in the state 1, 2, 4, 5, 7, and 8, the switching frequency of each active gateway in the average unit time is as formula (9)

$$f_{sw} = \frac{P_{SW}}{2T} = \frac{\pi_1 + \pi_2 + \pi_4 + \pi_5 + \pi_7 + \pi_8}{2T} \quad (9)$$

3.4 Average Gain Analysis

Transmit gain occurs when a switching event occurs. As shown above, consider transmit gain at 6 kinds of states. Assume that the probability density function of the attenuation on the GW_i link is $f_i(A)$, and transmit gain at state i is G_i , so the average gain G is as formula (10)

$$\begin{aligned} G &= \pi_1 G_1 + \pi_2 G_2 + \pi_4 G_4 + \pi_5 G_5 + \pi_7 G_7 + \pi_8 G_8 \\ &= \left(\frac{\pi_1}{P_1}\right) \int_{\beta_3}^{\infty} \int_0^{\infty} f_3(A_3) f_1(A_1) (A_1 - A_3) dA_3 A_1 + \left(\frac{\pi_2}{P_2}\right) \int_{\beta_2}^{\infty} \int_0^{\infty} f_3(A_3) f_2(A_2) (A_2 - A_3) dA_3 A_2 \\ &\quad + \left(\frac{\pi_3}{P_3}\right) \int_{\beta_3}^{\infty} \int_0^{\infty} f_2(A_2) f_3(A_3) (A_3 - A_2) dA_2 A_3 + \left(\frac{\pi_4}{P_1}\right) \int_{\beta_1}^{\infty} \int_0^{\infty} f_2(A_2) f_1(A_1) (A_1 - A_2) dA_2 A_1 \\ &\quad + \left(\frac{\pi_5}{P_2}\right) \int_{\beta_2}^{\infty} \int_0^{\infty} f_1(A_1) f_2(A_2) (A_2 - A_1) dA_1 A_2 + \left(\frac{\pi_6}{P_3}\right) \int_{\beta_3}^{\infty} \int_0^{\infty} f_1(A_1) f_3(A_3) (A_3 - A_1) dA_1 A_3 \end{aligned} \quad (10)$$

4 Numerical Result and Discussion

The mean and variance of rainfall fading are 5 dB and 25 dB respectively. For each strategy, each gateway has a simulation of 1,000,000 times between 20 km and 200 km. 200 km is represented by dots, and 20 km is represented by stars. The simulation results are as follows:

In Fig. 2, we compare the outage probability of the three strategies under different thresholds. We can be informed that TH-SSC strategy is worse than SSC strategy, but better than single gateway strategy in bad conditions. However, TH-SSC is close to SSC strategy in good conditions.

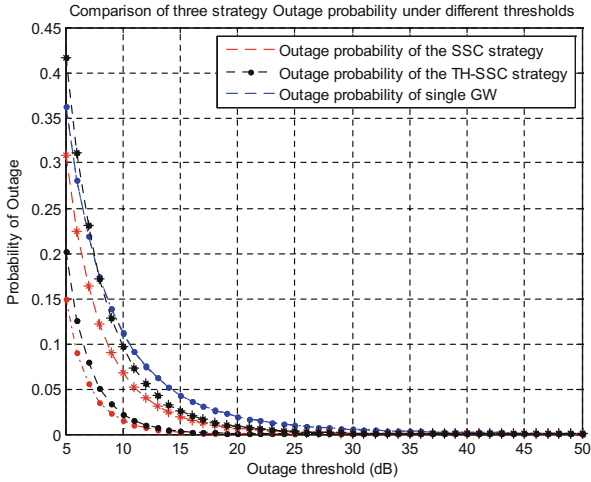


Fig. 2. Comparisons of three strategy’s outage probability

In Fig. 3, we show the performance of outage probability under different thresholds, which illustrates that TH-SSC strategy is better than SSC strategy, especially in bad conditions.

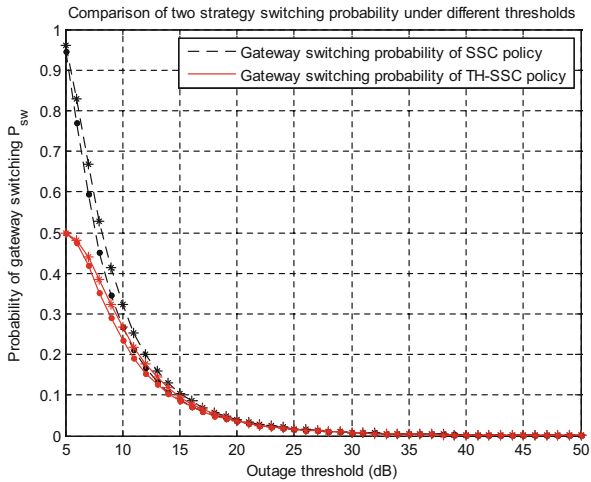


Fig. 3. Comparisons of two strategy’s switching probability

In Fig. 4, we present the transmit gain of SSC and TH-SSC strategies under different thresholds. It is obvious that TH-SSC strategy is much better than SSC strategy.

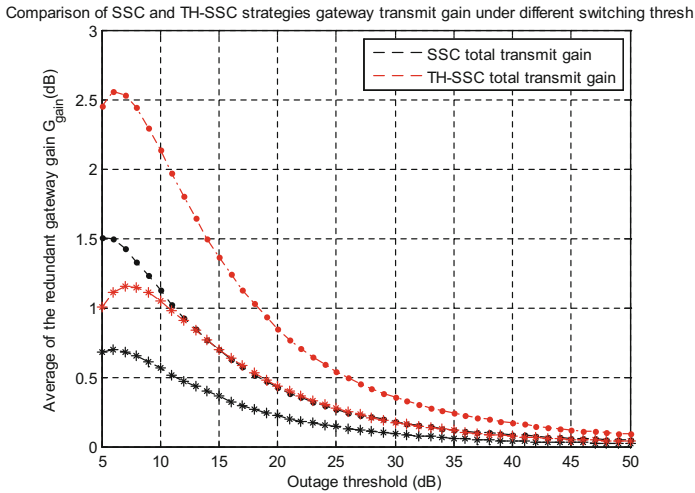


Fig. 4. Comparisons of two strategy's transitions gain

5 Conclusion

In this paper, a modified switch and stay scheme for Q/V band feeder link has been studied, which is a strategy include two active gateways and one redundant gateway and don't need sort by the received signal to noise ratio of different gateways. Through simulation, it can be seen that TH-SSC strategy is much better than SSC in transmit gain and switching probability, but in bad channel conditions, it is worse than SSC strategy in outage probability. It is further seen that advantages of TH-SSC is mainly in lower costs.

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