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Session 1 – Track4

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A Study on Adjacent Satellite Interference Cancellation in Dual-Contact Satellite Systems

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Introduction

- Due to the frequency congestion of the X-band limited up to 375 MHz, there is a frequency overlap among many earth observation satellites and it can cause serious interferences between those satellites.
- The performance for the target satellite is severely degraded in case that the offset angle between the two satellites was within the first null point of each antenna radiation pattern.
- The conventional receivers generally either ignore the interference or successively detect and then cancel the interference from the received signal, assuming that the desired signal and/or the interference signal are Gaussian.
- When the receiver can take into account the modulation formats of the desired signal and the interference signal, the performance can be enhanced with the aid of joint detection.
- The joint minimum-distance (JMD) detector with a lower-complexity approximation of the ML detector can decode correctly the desired signal without error floors in which it requires the knowledge of the modulation scheme and the channel gain for the interferer.
- Since the very limited numbers of the satellites affect the target satellite and the receiver can know the information for the signal characteristics of the adjacent satellite in advance, the JMD can be applicable in dual-contact satellite systems.

Dual-Contact Satellite Systems

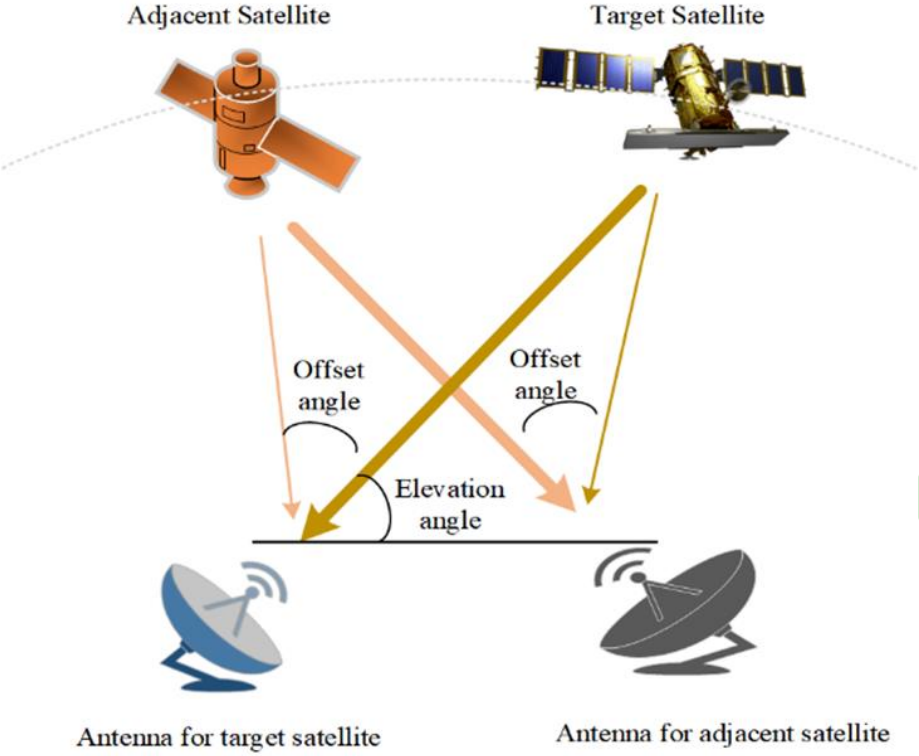
- The received signal from target satellite & adjacent satellite

$$y_1 = \alpha_{1,1} h_{1,1} x_1 + \alpha_{1,2} h_{1,2} x_2 + w_1$$

$$y_2 = \alpha_{2,1} h_{2,1} x_1 + \alpha_{2,2} h_{2,2} x_2 + w_2$$

$h_{i,j}$, the channel from transmitter j to receiver i.
w : Gaussian noise
$\alpha_{i,j}$, the antenna gain, has the maximum gain for $i = j$ but $\alpha_{i,j}$ has a different relative antenna gain depending on the antenna radiation pattern corresponding to the offset angle for $i \neq j$.

*An offset angle is defined by the angle difference between the target satellite and the adjacent satellite



Dual Satellite System Configuration

Antenna Radiation Pattern Model

- JPL peak envelope model
  - Mathematical Gain Models of Large-aperture Earth Station Antennas for Space Research Service
  - New model providing peak envelope for all frequency ranges of interest.

$$G(\theta) = G_0 - 3\left(\frac{\theta}{\theta_{hp}}\right)^2 \quad \text{for } 0^\circ \le \theta \le \theta_1$$

$$G(\theta) = G_0 - G_1 \quad \text{for } \theta_1 < \theta \le \theta_2$$

$$G(\theta) = G_0 - G_1 - G_2 \log_{10}\left(\frac{\theta}{\theta_2}\right) \quad \text{for } \theta_2 < \theta \le \theta_3$$

$$G(\theta) = G_3 \quad \text{for } \theta_3 < \theta \le 80^\circ$$

$$G(\theta) = G_3 + 5 \quad \text{for } 80^\circ < \theta \le 120^\circ$$

$$G(\theta) = G_3 \quad \text{for } 120^\circ < \theta \le 180^\circ$$

θ is the polar angle from boresight

$$G_0 = 10 * \log_{10}[\eta_a (\frac{\pi D}{\lambda})^2] - 4.343(\frac{4\pi h_{rms}}{\lambda})^2$$

$$G_1 = 17$$

$$G_2 = 27 + 10[\log_{10}(\eta_a) - \log_{10}(60\frac{h_{rms}}{\lambda})]$$

$$G_3 = -10$$

$$\theta_{hp} = 0.5\frac{C_{hp}}{(D/\lambda)} \quad (65 \le C_{hp} \le 70, \text{nominal value=69})$$

$$\theta_1 = \theta_{hp}\sqrt{\frac{G_1}{3}}$$

$$\theta_2 = \theta_{hp} 10^{\frac{G_1}{G_2}} \sqrt{\frac{G_2}{36}}$$

$$\theta_3 = \theta_2 10^{\frac{G_0 - G_1 - G_3}{G_2}}$$

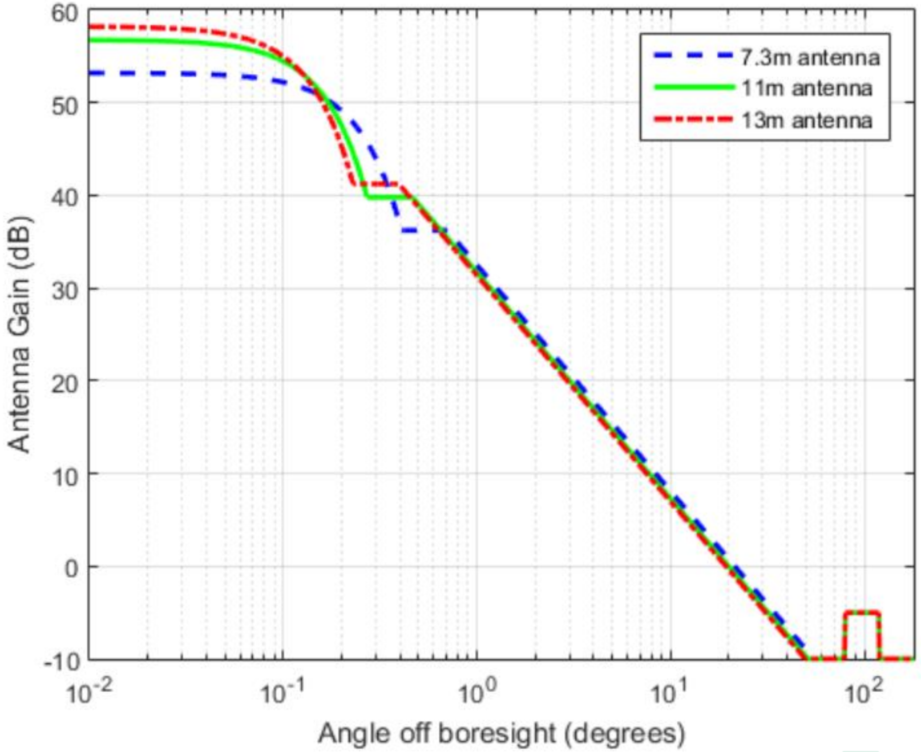
Offset Angle & Antenna Radiation Pattern

- Calculated by JPL peak envelope model

Table. Offset angle for HPBW, 1st null point, and 1st side lobe of 7.3 m, 11 m and 13 m antenna at 8,260MHz.

Degrees	7.3 m antenna	11 m antenna	13 m antenna
HPBW	0.1716	0.1139	0.0964
1st null point	0.4086	0.2712	0.2294
1st side lobe	0.7028	0.4664	0.3946

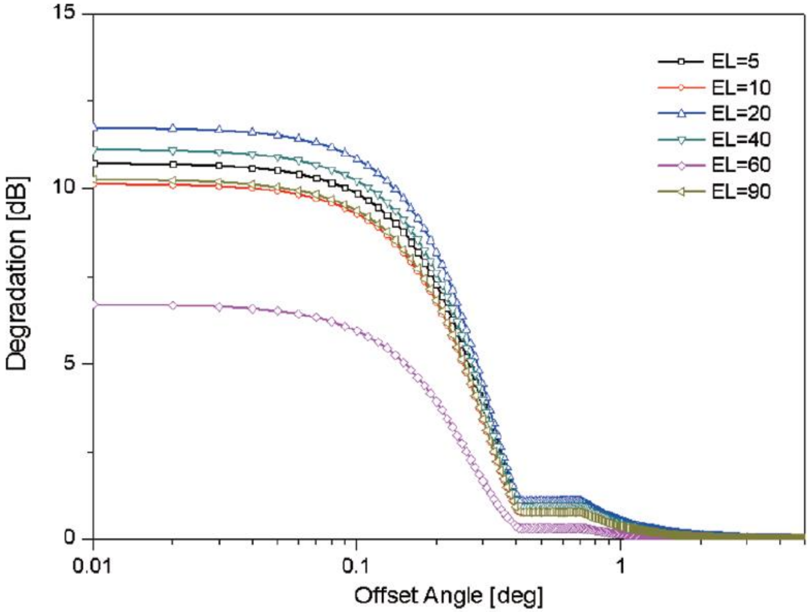
- ➢ Very sharp radiation pattern for all antennas
- ➢ Much sharper radiation pattern for the bigger size of antenna



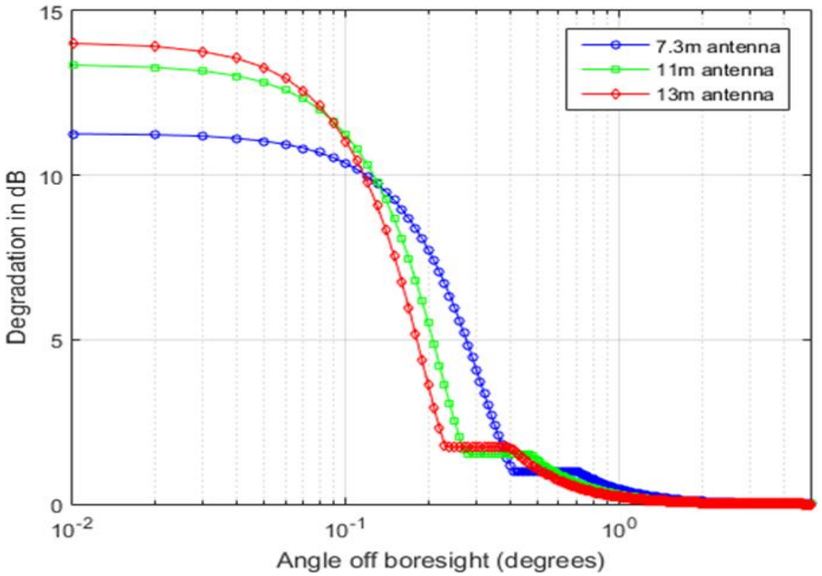
Antenna Gain vs. angle off boresight

Degradation by Adjacent Satellite Interference

- Example for the performance degradation



Degradation for 7.3m antenna



Degradation vs. angle off boresight

- ➢ The performance degradation is severely increased within the 1st null point and it is not possible to decode properly the data.

Detectors (1/2)

- II(Interference-Ignorant) Detector
  - II detector simply divides the received signal by the direct channel gain then maps it to the closest point of the signal constellation of target satellite.
  - Interference signal from an adjacent satellite is lumped together with the background noise.
- SIC Detector
  - For the dual-contact satellite systems, although the detector for a target satellite is interested only in x_1 of a target satellite signal , it can first get an estimate, $\hat{x}_2$, of x_2 by treating x_1 as noise, then detect x_1 based on $y - \hat{h}_2 x_2$ by mapping $y - h_2 \hat{x}_2$ to the closest constellation point scaled by channel gain, h_1.

Detectors (2/2)

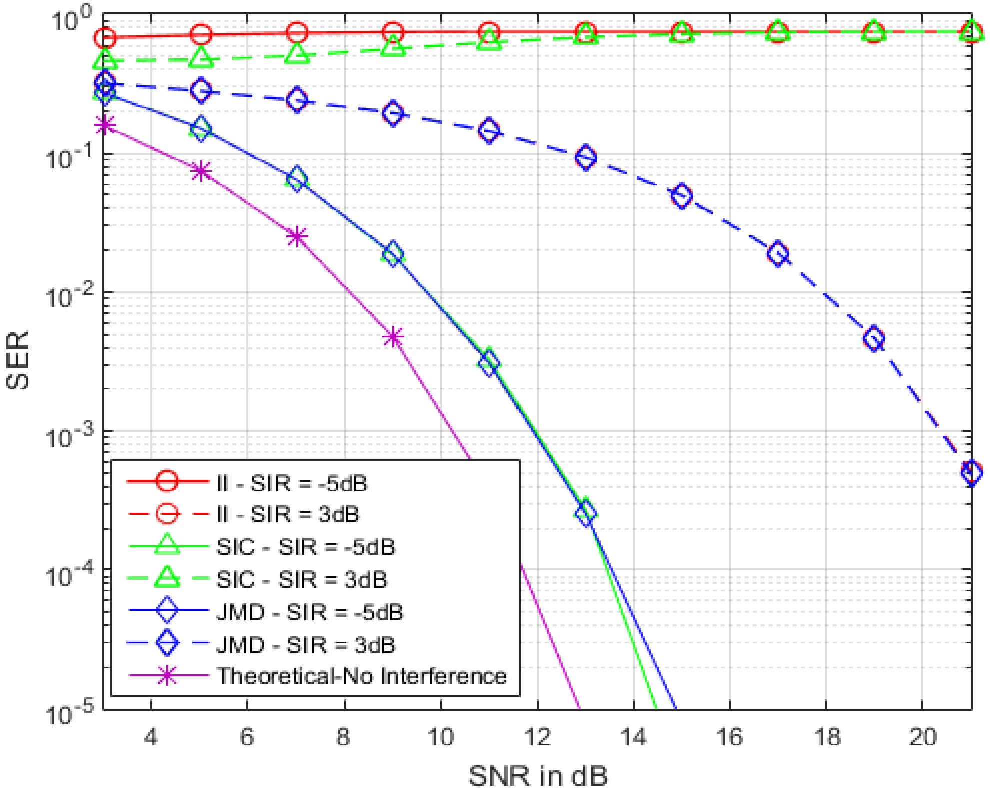
- Optimal ML Detector
  - Discrete signal constellation information of two satellites is taken into account.

$$\hat{x}_1(y_1) = \underset{x_1}{\operatorname{argmax}} \sum_{m_2=0}^{M_2-1} \cdot exp\left(-\frac{\left|y_1 - \alpha_{1,1}h_{1,1}x_1 - \alpha_{1,2}h_{1,2}x_{2,m_2}\right|^2}{N_0}\right)$$

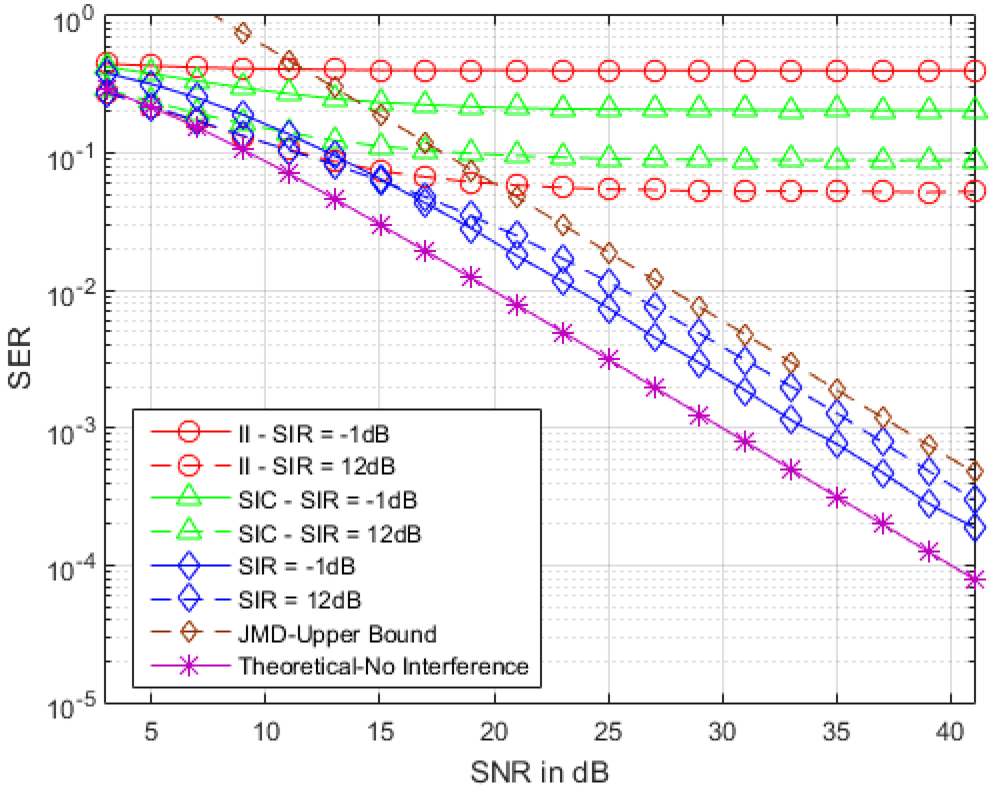
- JMD Detector
  - Interested in detecting only one target signal.
  - Not depending on the correct estimate of the interference signal

$$\hat{x}_1(y_1) = \underset{x_1}{\operatorname{argmin}} \left[\min_{x_2,\cdots,x_K} \left|y_1 - \alpha_{1,1}h_{1,1}x_1 - \sum_{k=2}^{K} \alpha_{1,k}\, h_{1,k}x_{k,m_k}\right|^2\right]$$

Simulation Results

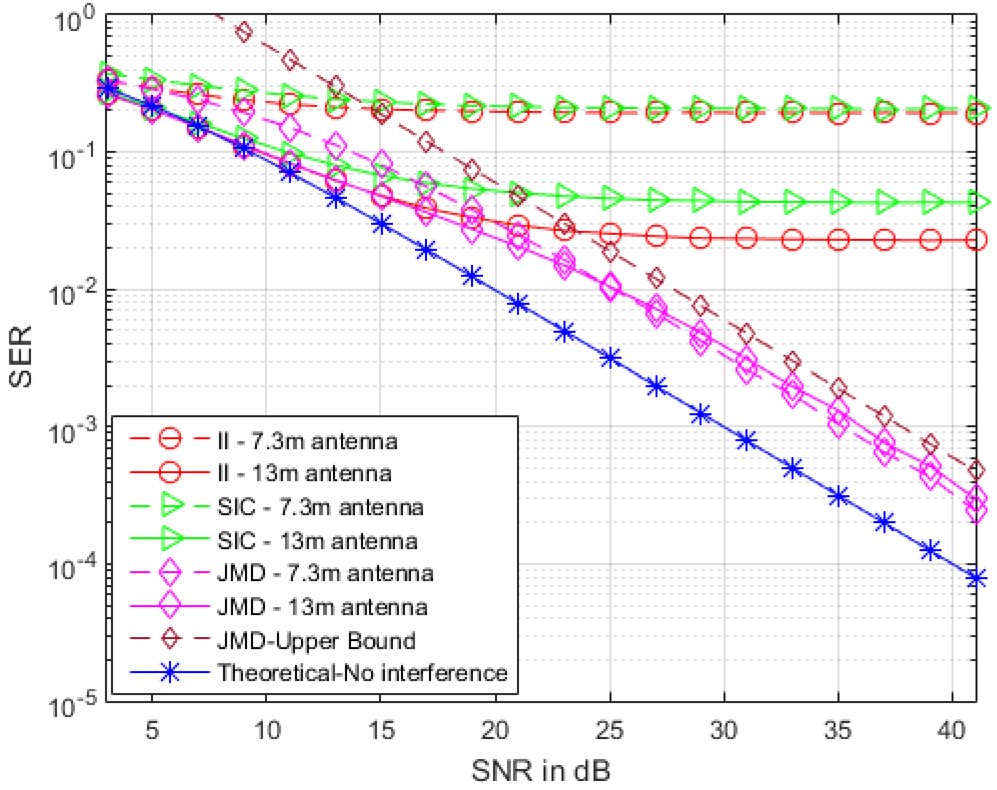


SER of 7.3m Antenna for II, SIC and JMD Detector in AWGN channel.

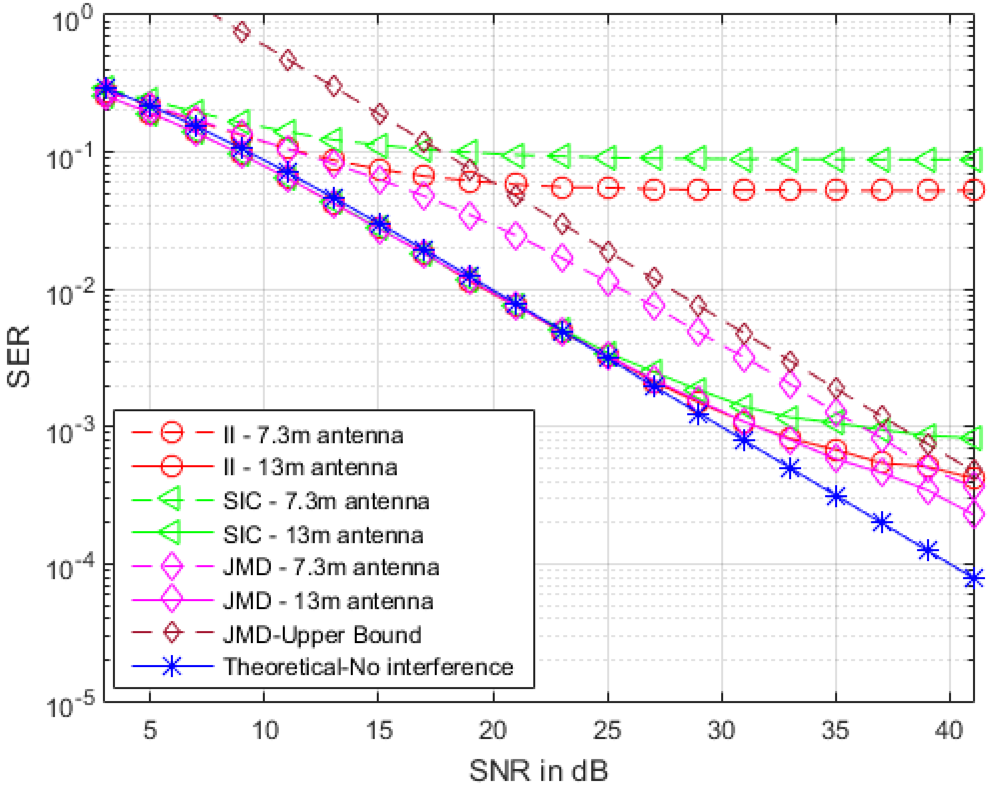


SER of 7.3m Antenna for II, SIC and JMD Detector in Rayleigh fading channel

Simulation Results



SER per antenna at an offset angle 0.1567 degrees (within HPBW for 7.3m antenna) in Rayleigh fading channel



SER per antenna at an offset angle 0.2428 degrees (between HPBW and 1st null point for 7.3m antenna) in Rayleigh fading channel

Conclusion

- The II detector and the joint interference-aware detectors such as SIC and JMD for dual-contact satellite systems were simulated.
- Both the II detector and the SIC detector showed the performance error floors in Rayleigh fading channel and for some SIR values.
- The JMD detector as an approximated ML detector has no performance error floors for the various conditions such as SNRs, SIRs and the channels.
- The JMD detector as the interference-aware detector can reduce the interference of an adjacent satellite thereby improving the receiver performance.