Three-hops UWAC based on SOFAR Plane: A Novel Relay Deployment Technique

Jiajie Xu, Mustafa A. Kishk, Mohamed-Slim Alouini

✉ : jiajie.xu.1@kaust.edu.sa

Introduction

In this paper, to improve the underwater communication capacity at a level of thousands of kilometres, we propose a three-hop underwater wireless acoustic communication (3H-UWAC) structure based on the Sound Fixing and Ranging (SOFAR) channel. The proposed 3H-UWAC consists of transmitters, relay stations (RSs), and receivers. RSs are set on the SOFAR plane at a known depth. The transmitter will send the information to the nearest first relay station (NFRS) on the SOFAR plane with a narrow beam width. Then, the NFRS will send the information to the nearest relay station to the receiver on the SOFAR plane with a narrow beam width, which is the nearest second relay station (NSRS). Tools from stochastic geometry are used to model the spatial distributions of transmitters', receivers', and RSs' locations. The coverage probabilities (CPs) of the three hops (transmitter to FRS, FRS to SRS, and SRS to receiver) are analyzed, and the final CP from a transmitter to a receiver through the 3H link is derived.

System Model

Based on experiments, A special channel was found, where the acoustic can propagate similar to a line is named SOFAR Channel (Sound Fixing and Ranging channel). It is defined as a horizontal layer of water in the ocean at which the speed of sound is at its minimum (it will be called the SOFAR plane in this paper). The system model named 3H-UWAC is shown in Figure 1.
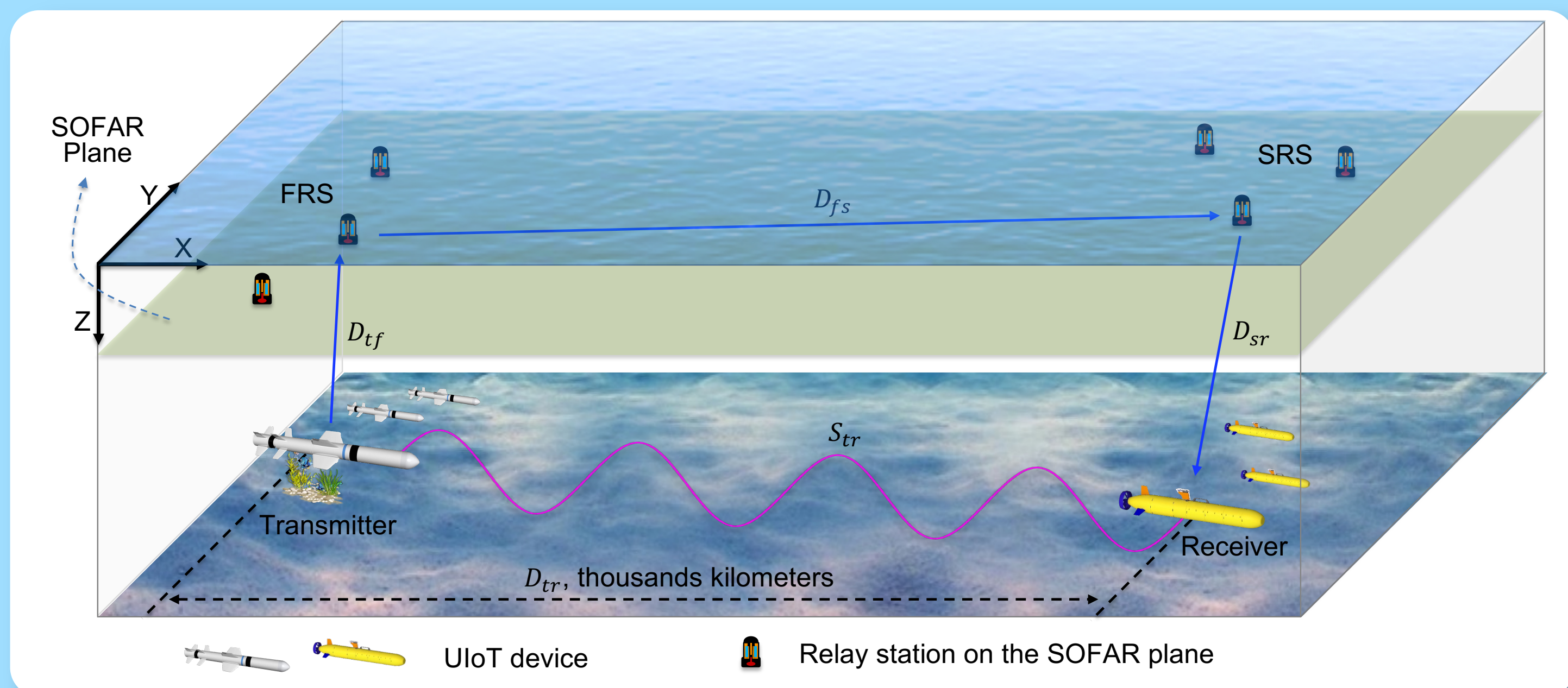

Figure 1: System Model.

All of the nodes are considered as random points and obey independent Poisson Point Processes (PPPs), and the three hops:

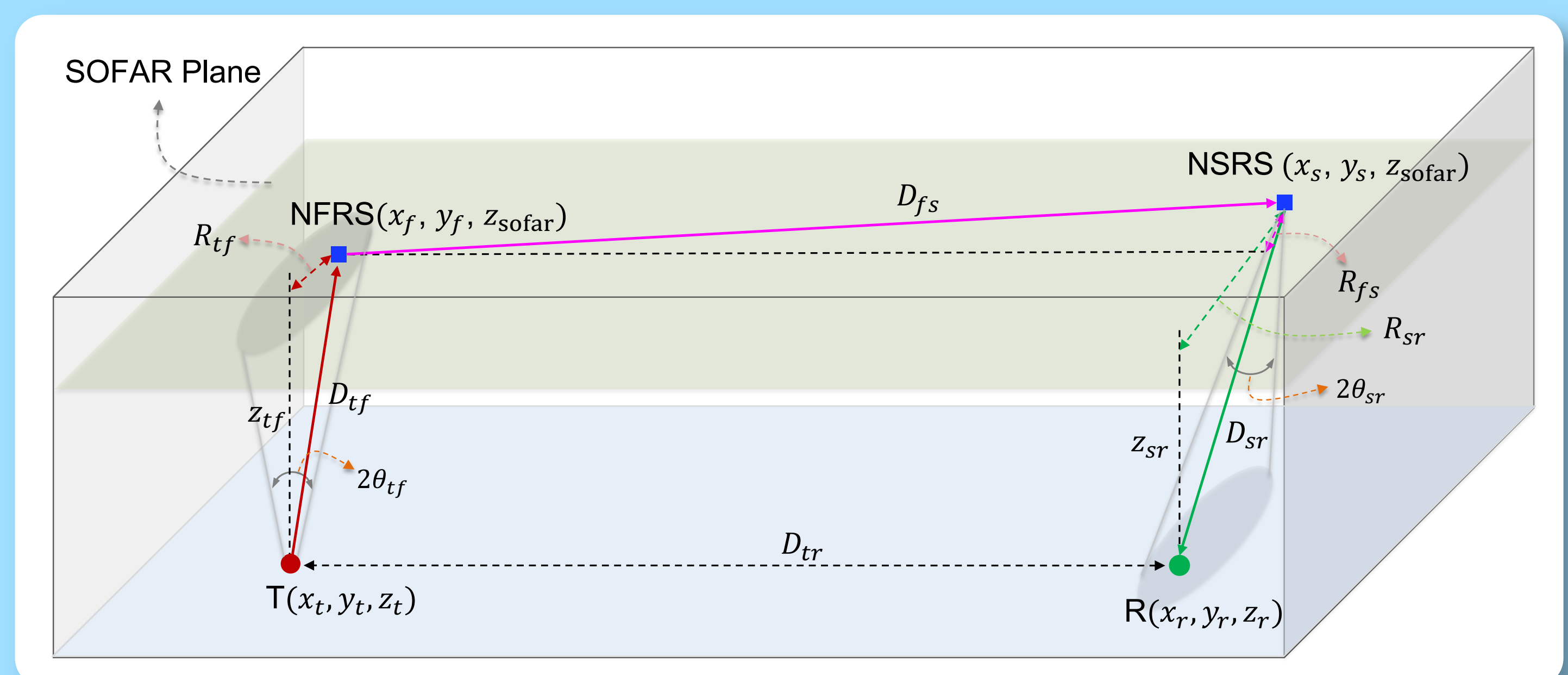- The transmitter to FRS
- FRS to SRS
- SRS to the receiver

Figure 2: The first hop and the second hop in 3H-UWAC.

$$P_{total}^{cov} = \mathbb{P}\big(Successful\ transmission\ from\ transmitter\ to\ NFRS,$$
$$Successful\ transmission\ from\ NSRS\ to\ receiver,$$
$$Successful\ transmission\ from\ NFRS\ to\ NSRS\big)$$
$$= \mathbb{P}\big(\text{SNR}_{tf} > \tau, R_{tf} \leq z_{tf}\tan(\theta_{tf}), \text{SNR}_{sr} > \tau, R_{sr} \leq z_{sr}\tan(\theta_{sr}),$$
$$\text{SNR}_{fs} > \tau, R_{fs} \leq \big(D_{tr} - R_{tf}\cos(A) + R_{sr}\cos(B)\big)\tan(\theta_{fs})\big)$$
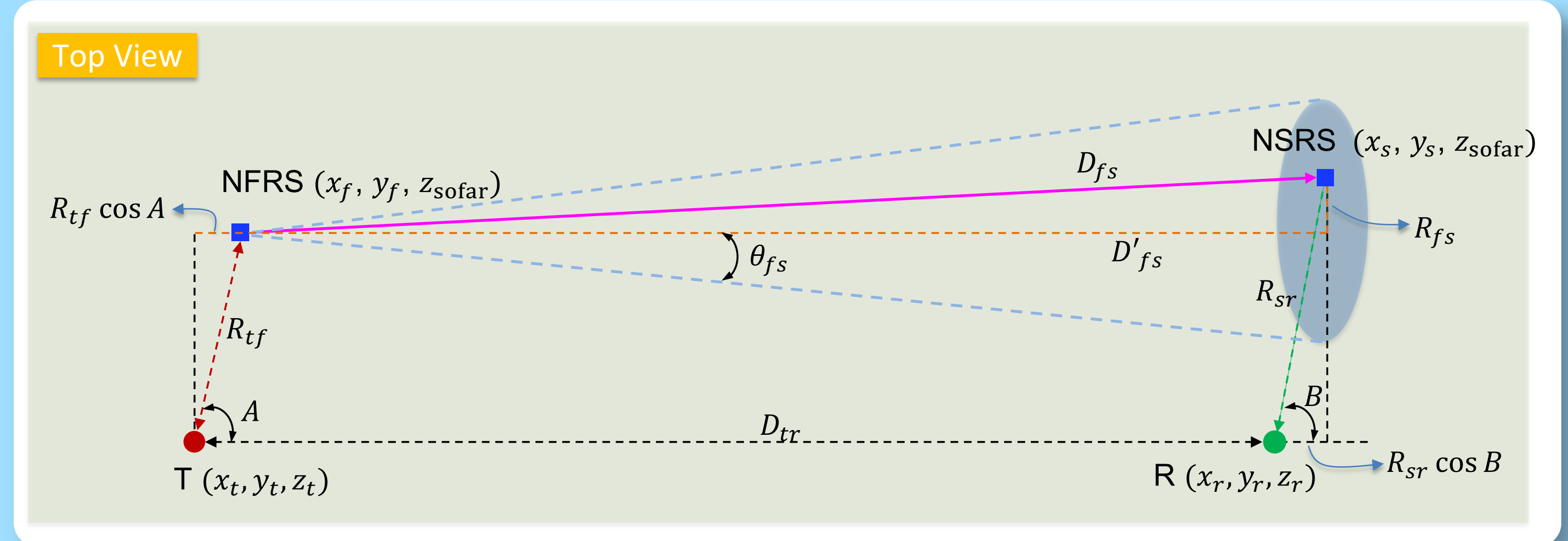

Figure 3: Top view of the second hop.

$$P_{fs}^{cov} = \int_0^\infty f_{R_{tf}}(R_{tf}) \int_0^\infty f_{R_{sr}}(R_{sr}) \int_0^{2\pi} f_A(a) \int_0^{2\pi} f_B(b)$$
$$\times \mathbb{1}\Big(\big(r_{tf}\sin(a) - r_{sr}\sin(b)\big)^2 \leq \mathcal{C}\big(r_{tf}, r_{sr}, a, b\big)\Big) da\,db\,dr_{tf}\,dr_{sr}$$
$$\triangleq \mathbb{E}_{R_{tf}, R_{sr}, A, B}\big[\mathcal{H}(R_{tf}, R_{sr}, A, B)\big]$$

Coverage Performance

According to our exploration of the mathematical calculation, SNR of the third hop will be less than the threshold τ when the depth of the receiver is greater than 6.8 km. Hence the CP of the third hop will equal 0, and the total CP will go to 0.

➤ For different values of z_t, with the increase of zr, CP will rise to the maximum value gradually.

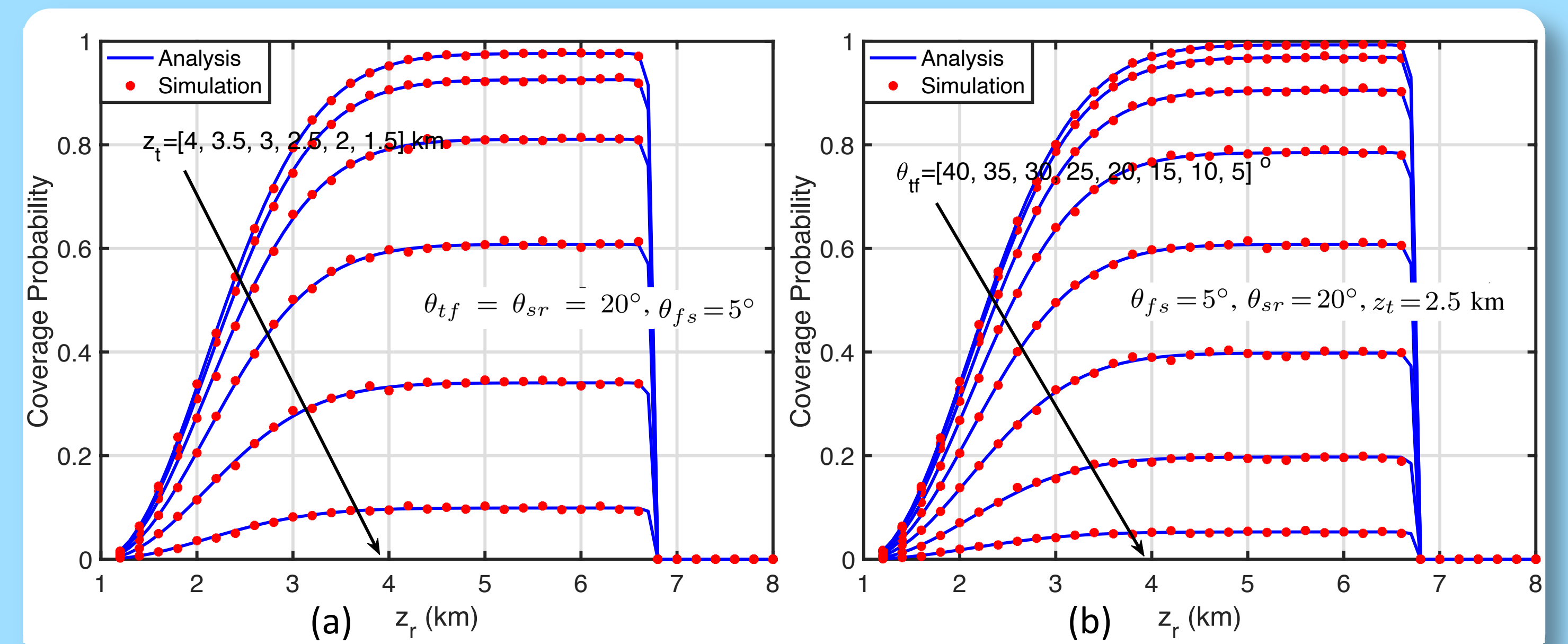➤ All the CPs dropped sharply to 0 when z_r goes to around 6.8 km.

Figure 4: CPs vary with different parameters.

Different CP performance of different VDA in the first hop, θ_{tf}, with given z_t = 2.5 km and z_r varies from 1.2 km to 8 km.

➤ A bigger θ_{tf} achieves a better coverage performance.

➤ A bigger VDA in the first hop, θ_{tf}, a better CP performance will be achieved in the first hop.
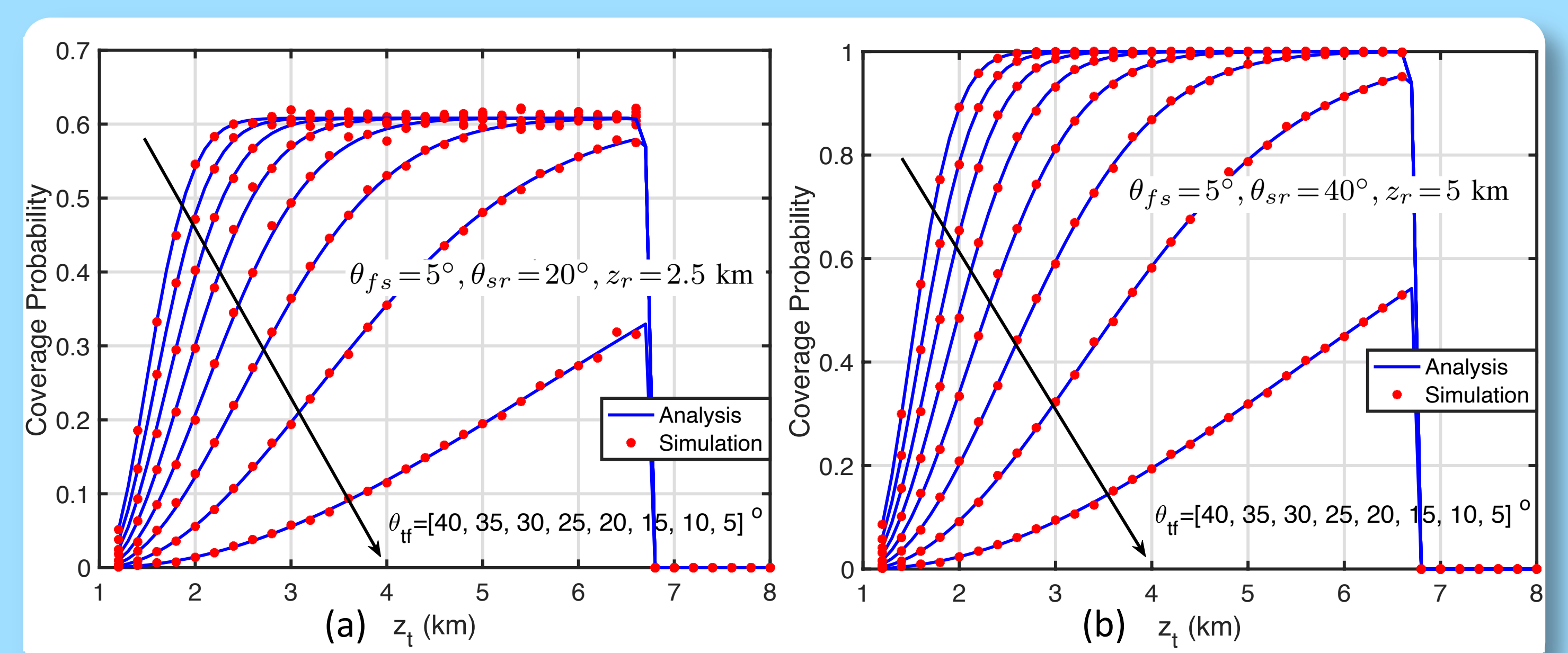

Figure 5: CPs varies with different θ_{sr} and z_r.

Change the parameters in the same hop (in the first hop) and identify the effects made by the two factors: (i) the depth of the transmitter and (ii) the VDA.

➤ When z_t is at a lower level, even if θ_{tf} is at a high level, for example, 40°, the CP is still very small.

➤ Comparing Fig. 5(a) and Fig. 5(b) further, we can find that θ_{sr} and z_r in the third hop affect the maximum CP of the system. Again, when z_t ups to 6.8 km, SNR of the first hop will lower the decoding threshold so that the CP will be 0.