Spectrum sharing method in satellite and terrestrial coexisting networks

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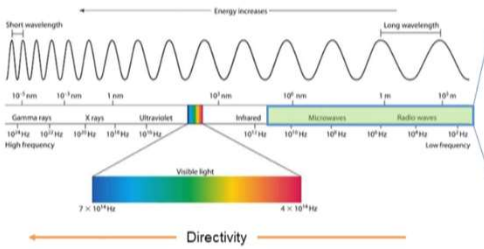
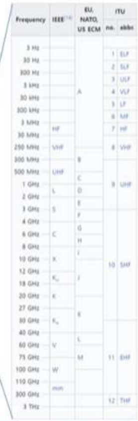
Revisit

EM wave in wireless communications

- Electromagnetic wave is used as an information carrier
  - $f = c/\lambda$
  - f: frequency / c: speed of light / λ: wavelength
  - EM wave 3 Hz to 300 GHz are exploited





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Principles of wireless communications

- Received signal in single input single output system

$$y = hx + n$$

Signal-to-Noise Ratio (SNR)

$$\mathrm{SNR} = \frac{|h|^2 P_{tx} E(|x|^2)}{N_0}$$

h: complex channel gain

x: signal input

n: additive white gaussian noise $\mathcal{CN}(0, \sigma^2)$

N_0: AWGN noise power, $N_0 = kT_0$

P_{tx}: Power of transmitter

Performance Metric

Efficiency
- Bandwidth/energy
- Bit/s/Hz
- Bits/channel use
- Bit/s/Joule

Reliability(Outage probability)
- Bit error rate (BER)
- Symbol error rate (SER)
- Frame error rate (FER)

$$C = \log_2(1 + \mathrm{SNR})$$

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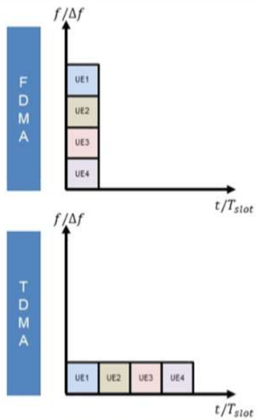
Principles of wireless communications

- **Resource block(UE)**
  - Fundamental unit of the wireless spectrum used to transmit data
  - Specific amount of time and frequency resources, typically in a grid-like fashion
- **Multiple access**
  - Orthogonal multiple access
    - Frequency division multiple access (FDMA)
    - Time division multiple access (TDMA)
  - Non-orthogonal multiple access (NOMA)



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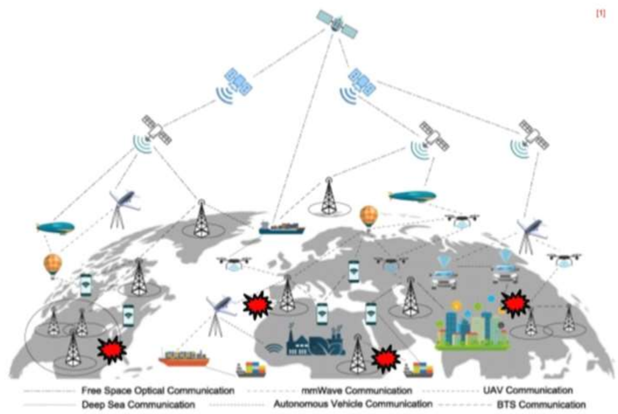
Future of wireless communications network



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Introduction

Background

- In wireless communications, satellite network (SN) is being spotlighted due to its numerous advantages(i.e., global coverage, low latency communication, scalability, and etc.)
- 3GPP is in a process of integrating satellite network in the mobile communication network
- In near future, the SN and terrestrial network (TN) will operate in a simultaneous manner

Problem

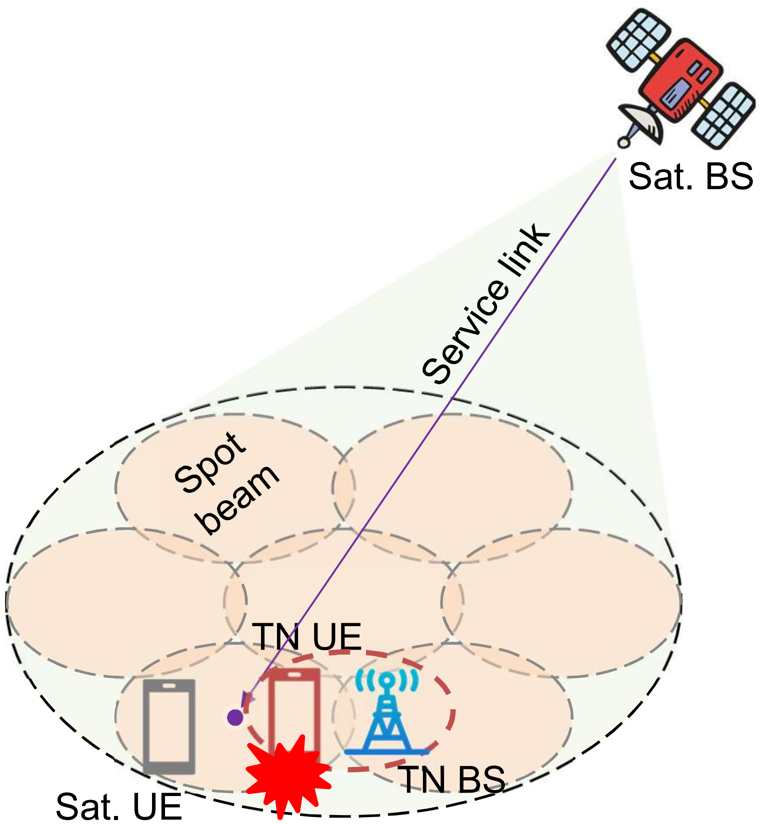
- The collision between two different system can arise due to spectrum sharing

Goal

- A spectrum sharing method for hybrid satellite and terrestrial network (HSTN) needs to be developed

CoMP NOMA for HSTN

Hybrid satellite and terrestrial network (HSTN) scenario



- TN-BS, Sat. BS, UE1, and UE2 are equipped with single antenna
- Sub-6GHz spectrum sharing
- The inter-system interference effect arises
- TN operates as conventional orthogonal multiple access (OMA) approach

CoMP NOMA for HSTN

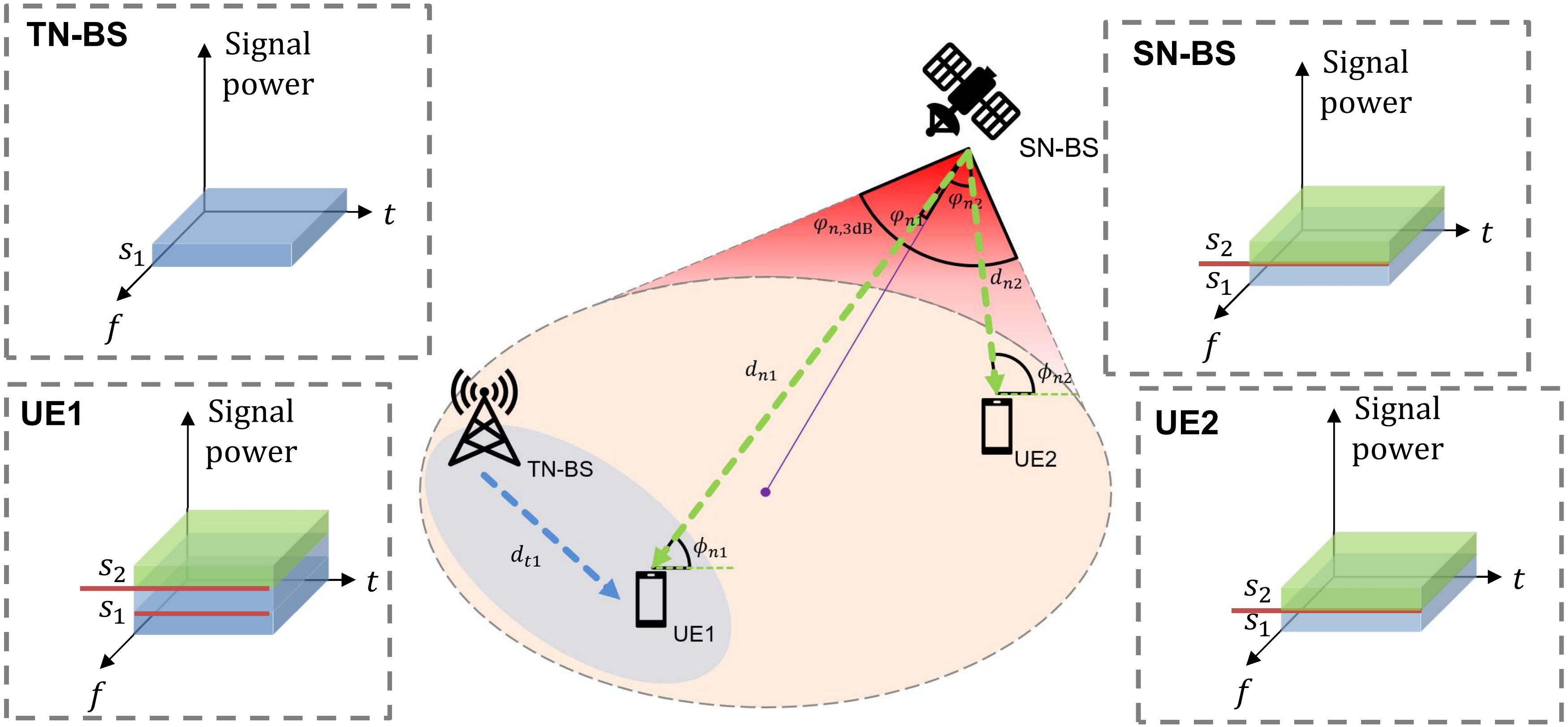
❖ System model

Non-orthogonal multiple access(NOMA)

- Power-domain NOMA
- Successive interference cancelation ($d_{n1} > d_{n2}$)

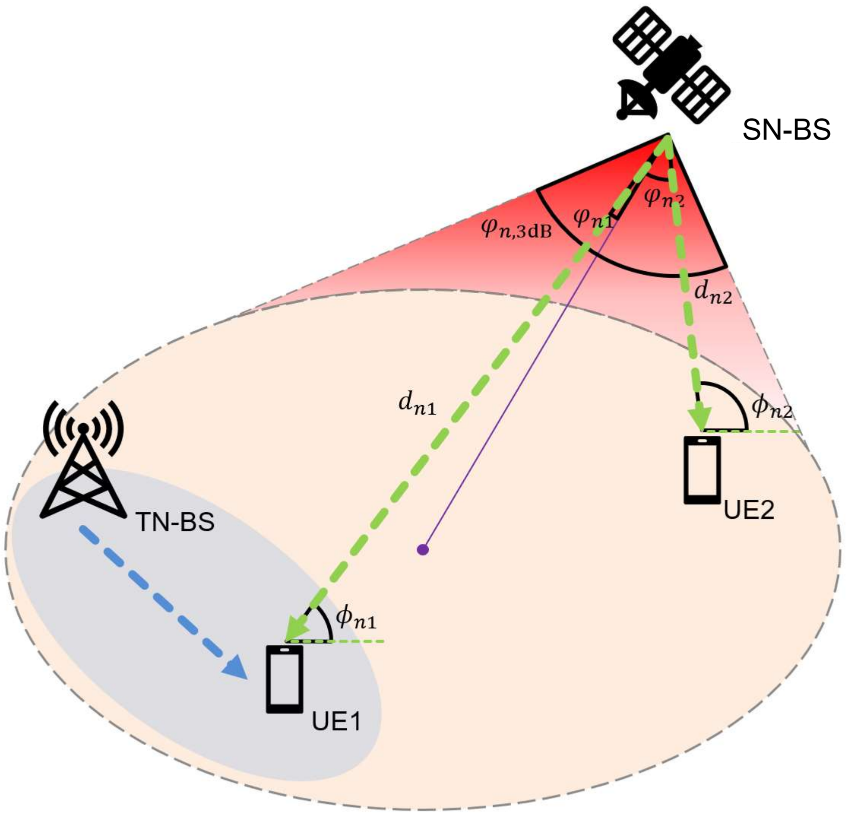
Coordinated multipoint(CoMP)

- Joint transmission CoMP



CoMP NOMA for HSTN

❖ **System model**



Received signal of UE1 & UE2

$$y_1 = P_t s_1 G_t L_{t1} h_{t1} G_u + P_n(b_1 s_1 + b_2 s_2) G_{n1} L_{n1} \sigma_n h_{n1} G_u + n_1$$

$$y_2 = P_n(b_1 s_1 + b_2 s_2) G_{n2} L_{n2} \sigma_n h_{n2} G_u + n_2$$

Signal-to-interference plus noise ratio

$$\mathrm{SINR}_1 = \frac{P_t G_t L_{t1} |h_{t1}|^2 G_u + b_1 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u}{b_2 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u + kTW}$$

$$\mathrm{SINR}_{2\to 1} = \frac{b_1 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u + kTW}$$

$$\mathrm{SINR}_2 = \frac{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{kTW}$$

Channel model for HSTN

❖ System model – SN

$$\mathrm{SINR}_1 = \frac{P_t G_t L_{t1} |h_{t1}|^2 G_u + b_1 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u}{b_2 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u + kTW}$$

$$\mathrm{SINR}_{2\to 1} = \frac{b_1 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u + kTW}$$

General antenna pattern

$$G_{nj}(\phi_{nj}) = G_{n,max}\left(\frac{J_1(u_j)}{2u_j} + 36\frac{J_3(u_j)}{{u_j}^3}\right)^2$$

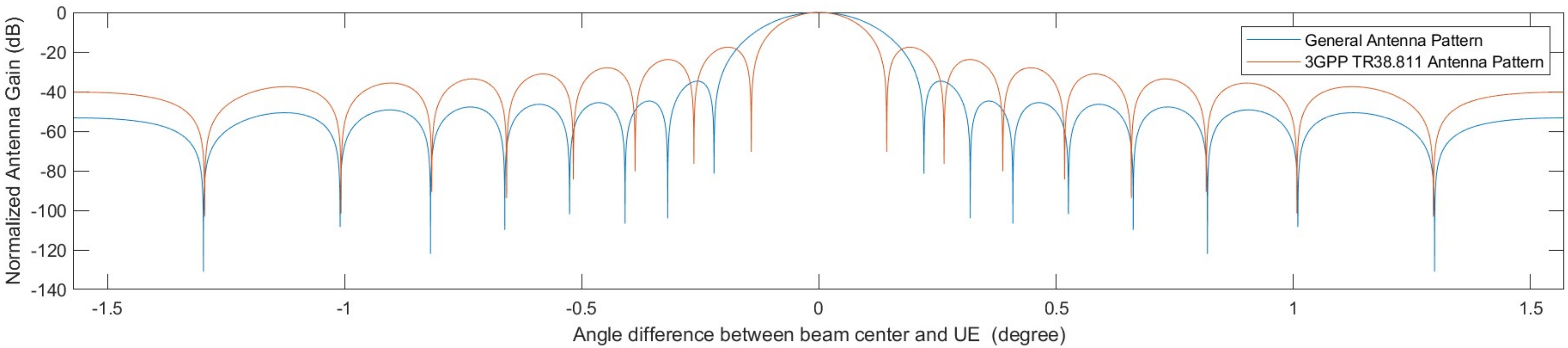
3GPP TR 38.811 antenna pattern ✔

$$G_{nj} = 4G_{n,\max}\left|\frac{J_1(u_j)}{u_j}\right|^2$$

$$u_j = 2.07123\left(\frac{\sin\varphi_{nj}}{\varphi_{3\mathrm{d}}}\right)$$

φ_{nj}: Angle difference btw. beam center of Sat. and j-th UE

$\varphi_{3\mathrm{d}}$: 3-dB beam angle of Sat.



Channel model for HSTN

❖ System model – SN

$$\mathrm{SINR}_1 = \frac{P_t G_t L_{t1} |h_{t1}|^2 G_u + b_1 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u}{b_2 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u + kTW} \qquad \mathrm{SINR}_{2\to 1} = \frac{b_1 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u + kTW}$$

Large scale path loss (3GPP TR 38.821)

$$L_{nj}[\mathrm{dB}] = 32.45 + 20\log_{10}(f_c) + 20\log_{10}(d_{nj})$$

Distance btw. J-th UE and Sat.

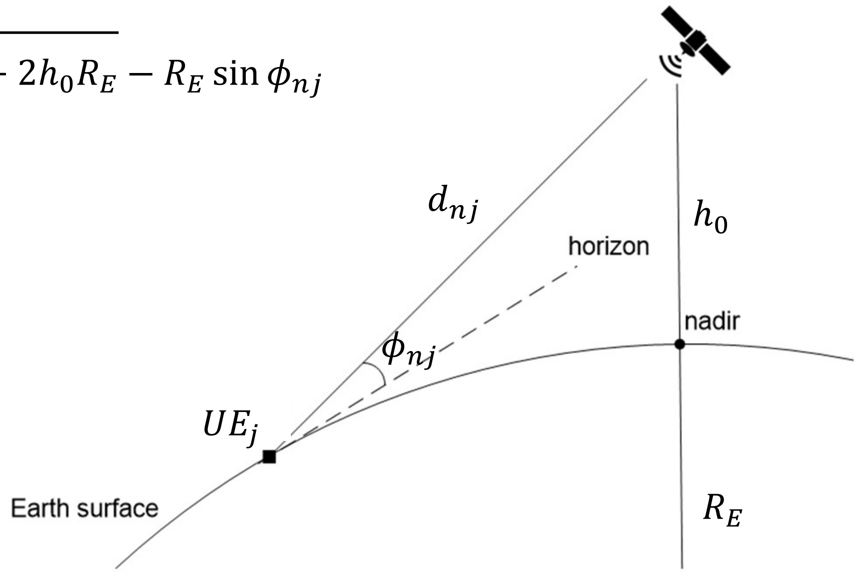
$$d_{nj} = \sqrt{R_E^2 \sin^2\phi_{nj} + h_0^2 + 2h_0 R_E} - R_E \sin\phi_{nj}$$

d_{nj}: Distance btw. UE j and Sat.

R_E: Earth radius

h_n: Satellite Altitude

ϕ_{nj}: Elevation angle btw. UE j and Sat.



Channel model for HSTN

❖ System model – SN

$$\mathrm{SINR}_1 = \frac{P_t G_t L_{t1} |h_{t1}|^2 G_u + b_1 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u}{b_2 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u + kTW} \qquad \mathrm{SINR}_{2\to 1} = \frac{b_1 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u + kTW}$$

Channel loss[1]

$$\sigma_n[\mathrm{dB}] = \sigma_{SF}(\phi_{nj}) + \sigma_A(\phi_{nj}, f_c) + \sigma_{SL}(f_c) + \sigma_P$$

Shadow fading margin[1]

Elevation Angle (deg.)	Dense urban scenario
	LOS
	σ_{SF} (dB)
10°	3.5
20°	3.4
30°	2.9
40°	3.0
50°	3.1
60°	2.7
70°	2.5
80°	2.3
90°	1.2

Atmospheric loss[1,2]

$$\sigma_A(\phi_{nj}, f_c) = \frac{A_{zenith}(f_c)}{\sin \phi_{nj}}$$

Scintillation (Ionospheric)[4]

$$\sigma_{SL}(f_c) = P_{fluc}(4\ \mathrm{GHz}) \times \frac{(f_c/4)^{-1.5}}{\sqrt{2}} = 1.1 \times \frac{0.5^{-1.5}}{\sqrt{2}} = 2.2\ \mathrm{dB}$$

$$P_{fluc} = 27.5 \cdot S_4^{1.26}$$

σ_{SF}: Shadow fading margin

σ_A: Atmospheric loss

σ_{SL}: Scintillation loss

σ_P: Polarization loss

ϕ_{nj}: Elevation angle btw. UE j and Sat.

[1] 3GPP TR 38.811 v15.2.0: "Study on New Radio (NR) to support non-terrestrial networks (Release 15)"
[2] ITU R P.676: "Attenuation by atmospheric gasses"

Channel model for HSTN

❖ System model – SN & TN

$$\mathrm{SINR}_1 = \frac{P_t G_t L_{t1} |h_{t1}|^2 G_u + b_1 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u}{b_2 P_n G_{n1} L_{n1} \sigma_n |h_{n1}|^2 G_u + kTW} \qquad \mathrm{SINR}_{2\to 1} = \frac{b_1 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u}{b_2 P_n G_{n2} L_{n2} \sigma_n |h_{n2}|^2 G_u + kTW}$$

Large Scale Path Loss (COST 231 Hata model) for TN

$$L_{t1} = 46.3 + 33.9 \log_{10} f_c - 13.82 \log_{10} h_t - a(h_u, f_c) + (44.9 - 6.55 \log_{10} h_u) \log_{10} d_{t1} + C_m$$

$$a(h_u, f_c)[\mathrm{dB}] = \begin{cases} 8.29(\log_{10} 1.54 h_u)^2 - 1.1, & if\ 150 < f_c \leq 200 \\ 3.2(\log_{10} 11.75 h_u)^2 - 4.97, & if\ 200 < f_c \leq 2000 \end{cases}$$

Small Scale Fading (Nakagami-m fading) for SN and TN

$$f_{|h_{ij}|^2}(x) = \frac{m_i^{m_i}}{\Omega_i^{m_i} \Gamma(m_i)} x^{m_i - 1} e^{-\frac{m_i}{\Omega_i} x}, \qquad x \geq 0 \qquad\qquad \Gamma(t) = \int_0^\infty x^{t-1} e^{-x} dx$$

m_i: Fading severity

Ω_i: Average power

G_u: UE Antenna gain

k: Boltzmann constant

T: Ambient temperature

W: System Bandwidth

h_u: effective UE antenna height

h_t: effective TN-BS antenna height

Simulation results

Performance

- Ergodic capacity of UE1
- Ergodic sum capacity of UE1 and UE2

Scenarios

1) TN [OMA]

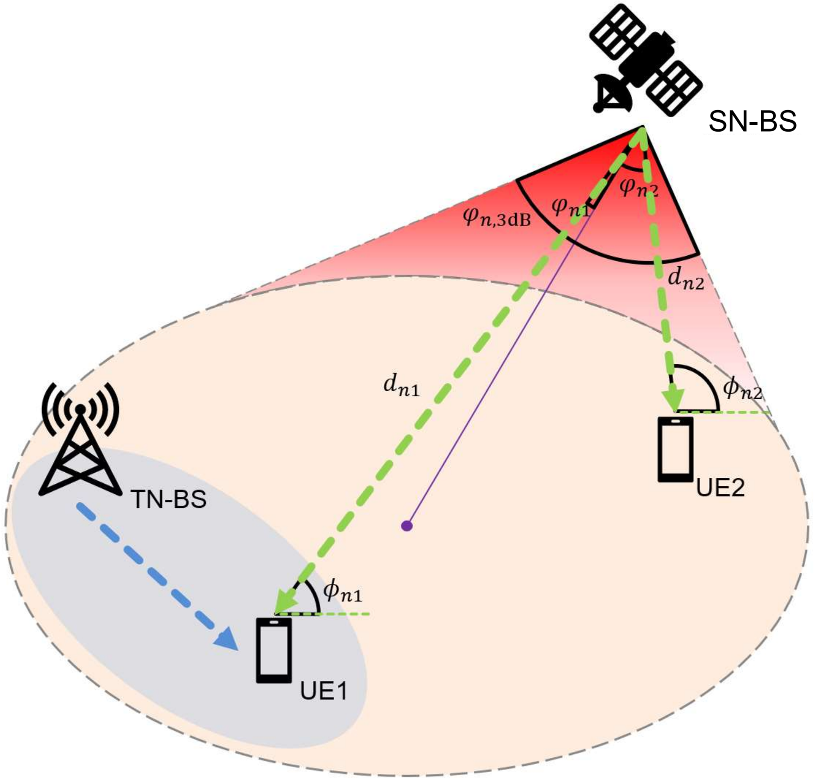
2) HSTN [no cooperation]: TN [OMA] + SN [OMA]

3) HSTN [no cooperation]: TN [OMA] + SN [NOMA]

4) HSTN [cooperation]: TN [OMA] + SN [CoMP NOMA]

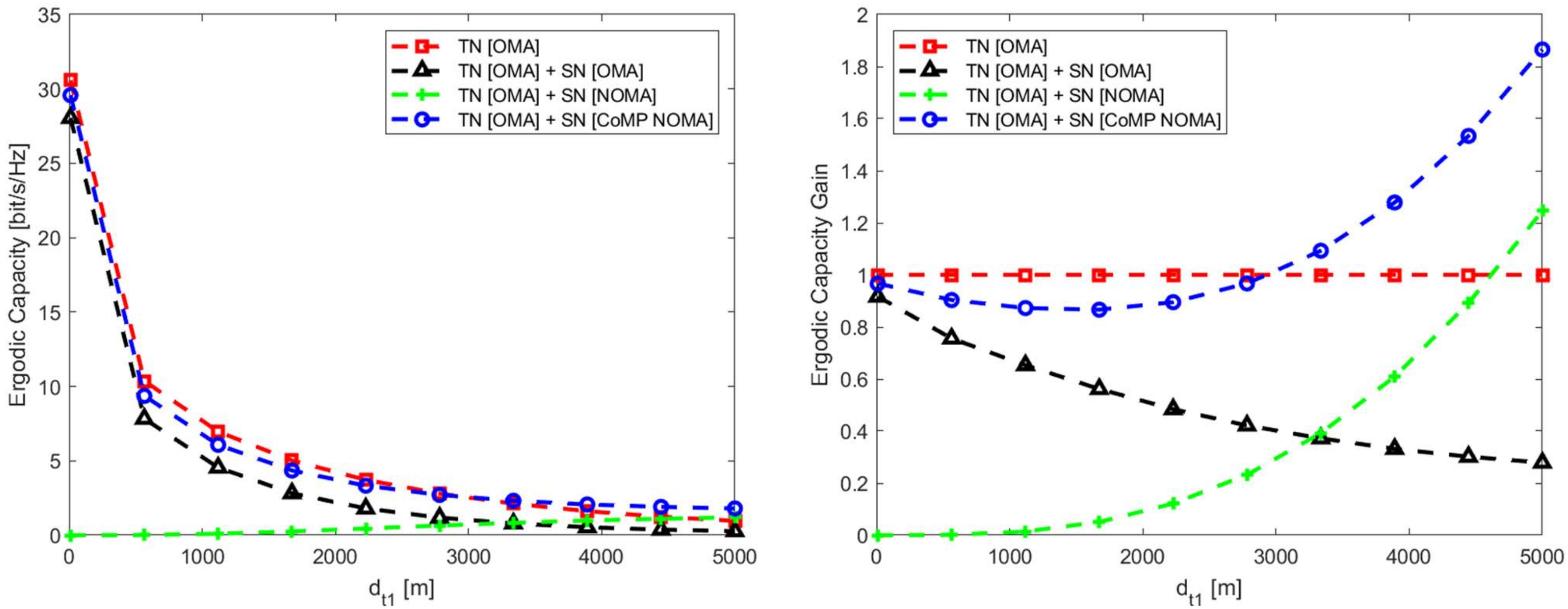
Simulation Parameters

Parameter	Value
Terrestrial Tx power, P_t	44 dBm
Satellite Tx power, P_n	44 dBm
Terrestrial antenna gain, G_t	14 dBi
Satellite antenna gain $G_{n,\max}$	30 dBi
Carrier frequency, f_c	2 GHz
System bandwidth, W	10 MHz
Satellite altitude, h_n	600 km
Power allocation coefficients, $\{b_1, b_2\}$	$\{0.8, 0.2\}$
Scintillation loss, σ_{SF}	2.2 dB
Atmospheric loss, σ_A	0.1 dB



Simulation results

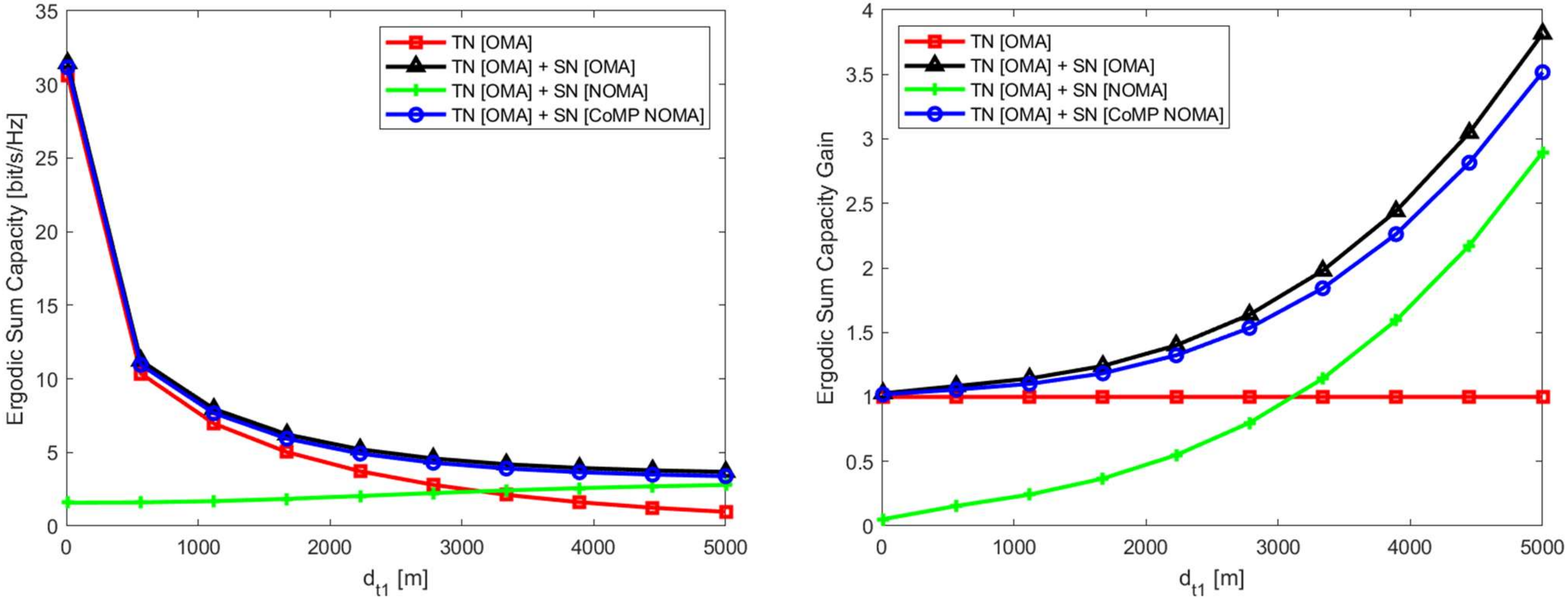
❖ Ergodic capacity of UE1



- d_{t1} indicates the distance between TN-BS and UE1
- Proposed model mitigates the ISI on TN

Simulation results

❖ Ergodic sum capacity of UE1 and UE2



- In TN [OMA] scenario, TN supports UE1 only
- TN [OMA] + SN [CoMP NOMA] network architecture achieves the higher network capacity compared to TN [OMA] scenario while it mitigates the ISI on TN

Summary

- Coordinated multipoint and non-orthogonal multiple access method for HSTN is proposed
- Our approach is validated by using 3GPP NTN standard parameters
- Proposed CoMP NOMA model for HSTN reduces the interference on TN user
- By using proposed scheme, the HSTN can be realized without changing the existing terrestrial network protocol

Thank you