KOREA UNIVERSITY

Cognitive Radio of Satellite Communication System

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Lab for Informatics,
communications and system

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  - Integrated Sensing and Communication
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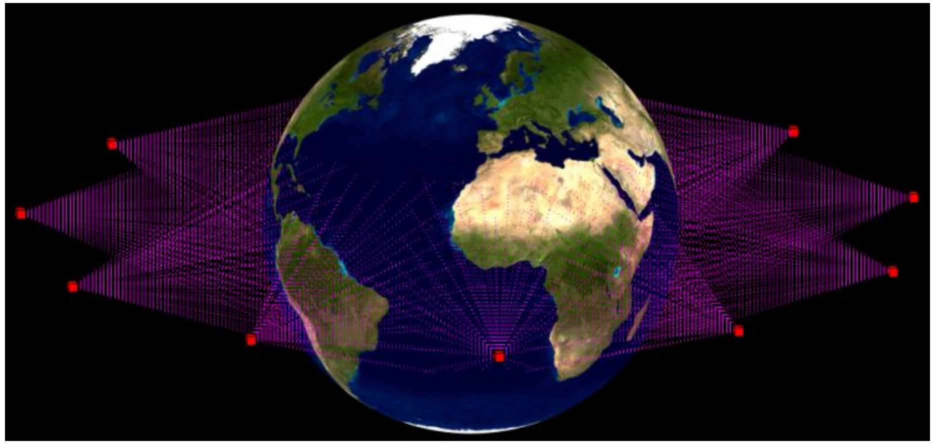
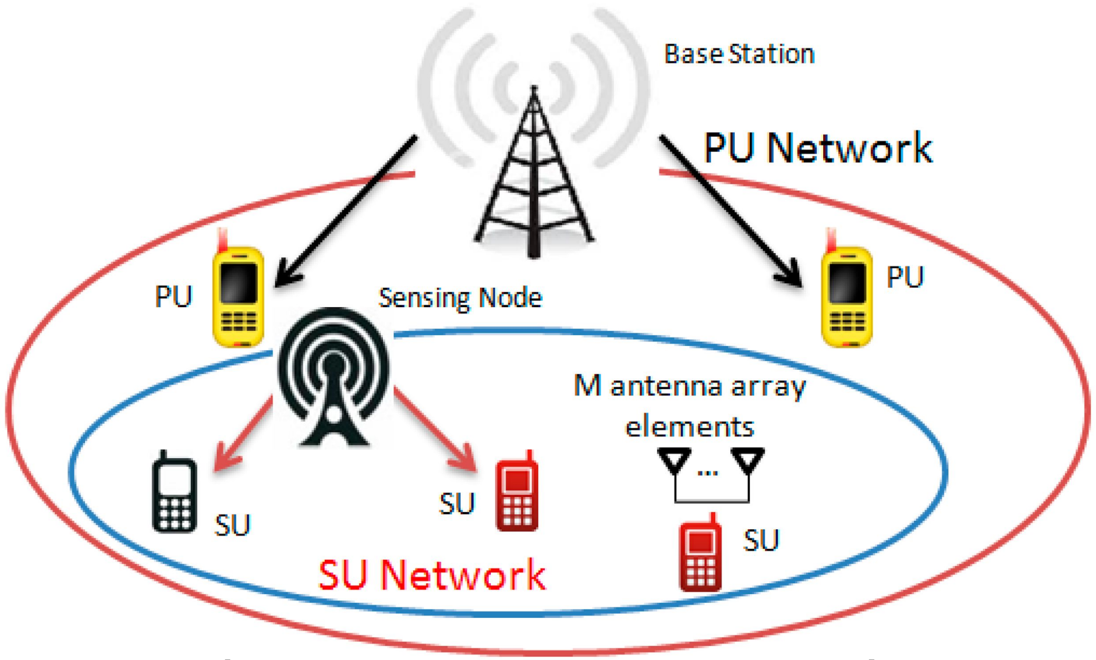
BackGround

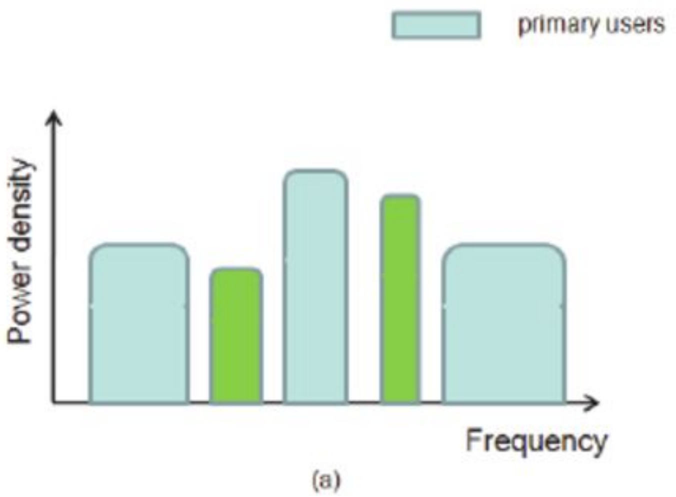


- Background : Traffic demand is increased rapidly and it incurs large problems (Challenges)
- Challenges :
  - Payload Design is going to be smaller (Power Resource is limited)
  - Constellation topology of LEO system causes interference
  - Spectrum resources is limited
- Resource allocation in Cognitive Radio can be solution

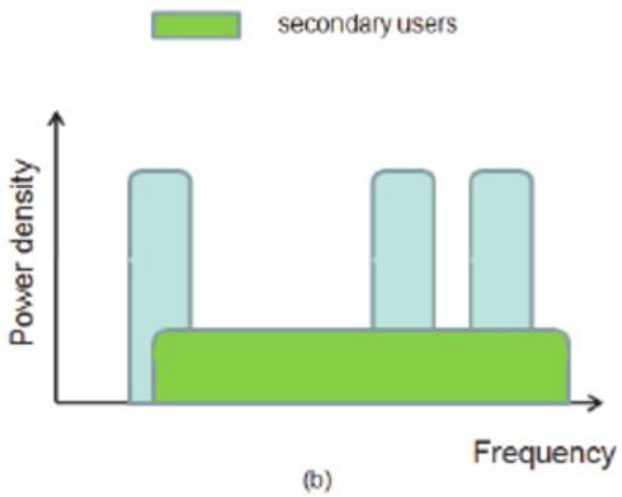
Cognitive Radio



(Cognitive Radio Schemes)



Overlay Method



Underlay Method

SU(Secondary User)s can access **PU**(Primary User)'s spectrum

: Sharing spectrum resources.

Problem 1 : Satellite-Terrestrial Network

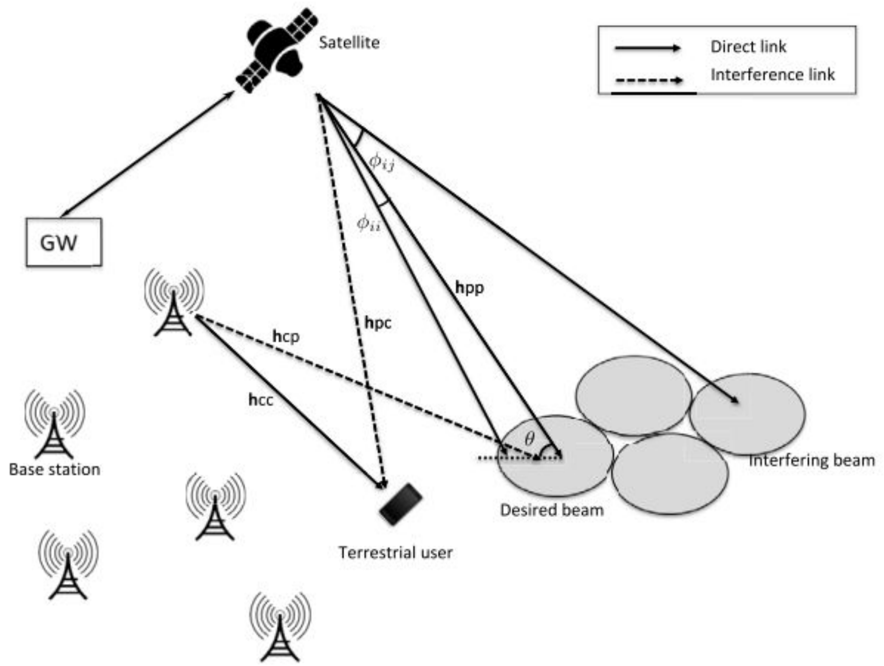
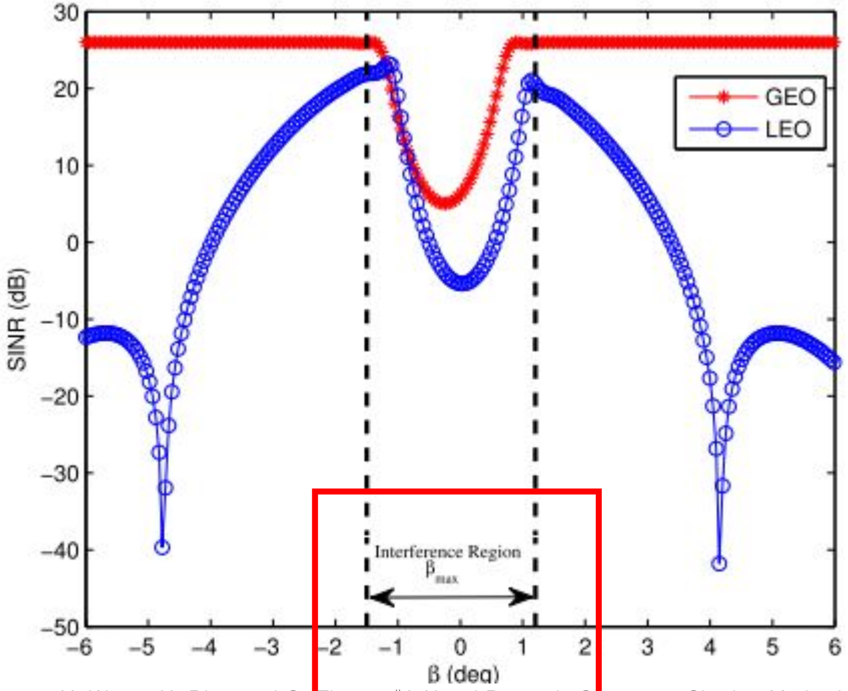


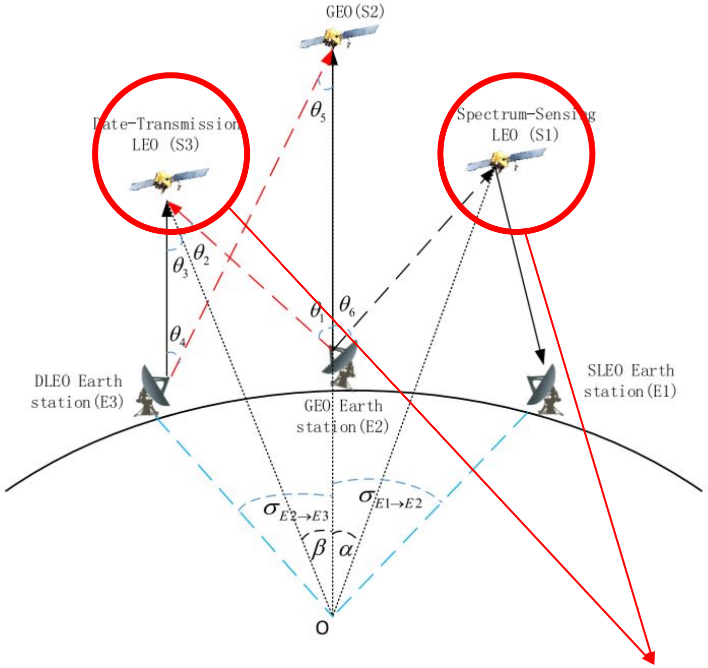
Fig. 1. An illustration of network set-up.

O. Y. Kolawole, S. Vuppala, M. Sellathurai and T. Ratnarajah, "On the Performance of Cognitive Satellite-Terrestrial Networks," in IEEE Transactions on Cognitive Communications and Networking

- Problem Setting
  - Satellite-Terrestrial networks has interference
  - Spectrum Limitation
- Solutions
  - Power Constraint to Interference(PCI)
  - Directional Beamforming to control Interference(DBI)
  - BS Thinning Process to restrict Interference(BTPI)

Problem 2 : Satellite-Satellite Network





Y. Wang, X. Ding and G. Zhang, "A Novel Dynamic Spectrum-Sharing Method for GEO and LEO Satellite Networks," in IEEE Access, vol. 8, pp. 147895-147906, 2020, doi: 10.1109/ACCESS.2020.3015487.

- Problem Setting
  - Satellite-Satellite networks has interference at specific region
  - Spectrum Limitation in each LEO satellites

- Solution
  - Coordination between DLEO and SLEO
  - Give leftover Spectrum resource from GEO to LEOs

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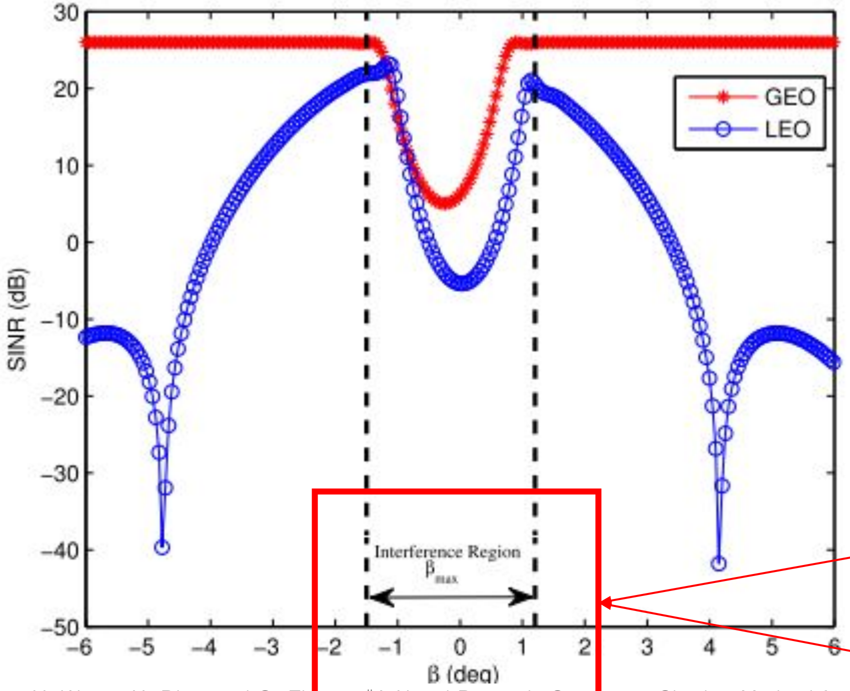
Problem 2 : Satellite–Satellite Network



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$$P_{S3} = P_{E3} h_{E3\to S3} = P_{E3} G^t_{E3} G^r_{E3}(\theta_3) \left(\frac{c}{4\pi f d_{E3\to S3}}\right)^2$$

$$I_{S3} = P_{E2} G^t_{E2\to S3}(\theta_1) G^r_{S3\to E2}(\theta_2) \left(\frac{c}{4\pi f d_{S3\to E2}}\right)^2$$

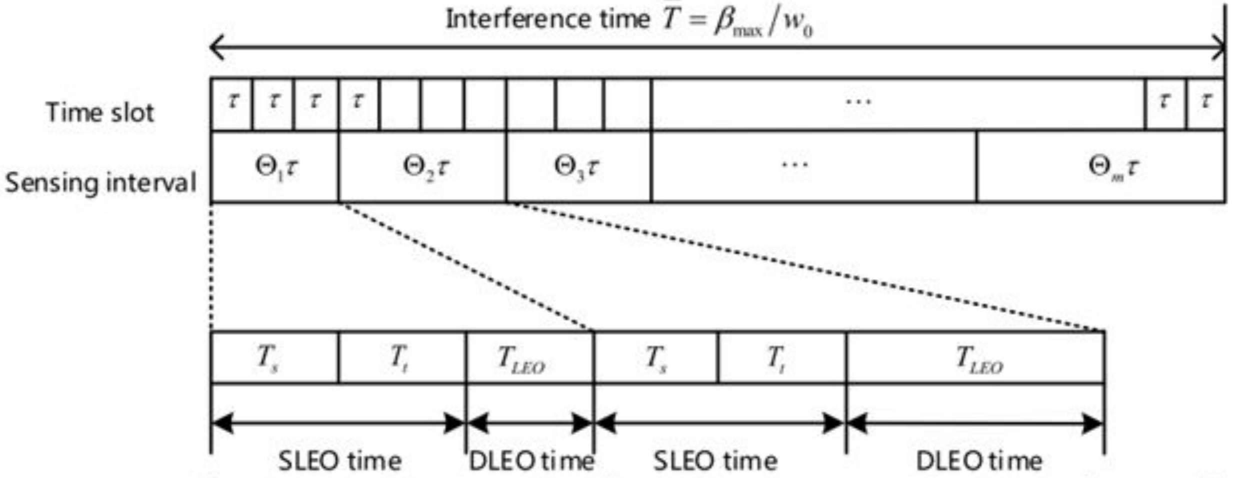
$$\boxed{\gamma_{S3}} = \frac{P_{S3}}{I_{S3} + N_0} = \frac{P_{S3}(\beta)}{I_{S3}(\beta) + N_0}$$

$$N_0 = kT_n B$$

$$\boxed{\gamma_{S2}} = \frac{P_{S2}}{I_{S2} + N_0} = \frac{P_{S2}(\beta)}{I_{S2}(\beta) + N_0}$$

- Specific region is interference region

Problem 2 : Satellite-Satellite Network



GEO state	Sening-result	Useful time		Interference time	Related Power
		Overlay	*Underlay*		
Idle: $P(H_0)$	Idle:$1-Pf_{S1}$	v_1	0	v_2	P^0_{E3}
Idle: $P(H_0)$	Busy:Pf_{S1}	v_1	v_2	0	P^1_{E3}
Busy: $P(H_1)$	Idle:$1-Pd_{S1}$	v_4	0	v_3	P^0_{E3}
Busy: $P(H_1)$	Busy:Pd_{S1}	v_3	v_4	0	P^1_{E3}

0

v_2

<Throughput of DLEO system>

$$\boxed{C_{00}} = \frac{1}{\Theta\tau}\left(v_1 \log_2\left(1+\frac{P^0_{E3}}{N_0}\right)\right)$$

$$\boxed{C_{01}} = \frac{1}{\Theta\tau}\left(v_1 \log_2\left(1+\frac{P^1_{E3}}{N_0}\right) + v_2 \log_2\left(1+\frac{P^1_{E3}}{I_{S3}+N_0}\right)\right)$$

$$\boxed{C_{10}} = \frac{1}{\Theta\tau}\left(v_3 \log_2\left(1+\frac{P^0_{E3}}{N_0}\right)\right)$$

$$\boxed{C_{11}} = \frac{1}{\Theta\tau}\left(v_3 \log_2\left(1+\frac{P^1_{E3}}{I_{S3}+N_0}\right) + v_4 \log_2\left(1+\frac{P^1_{E3}}{N_0}\right)\right)$$

<Sequence on GEO>

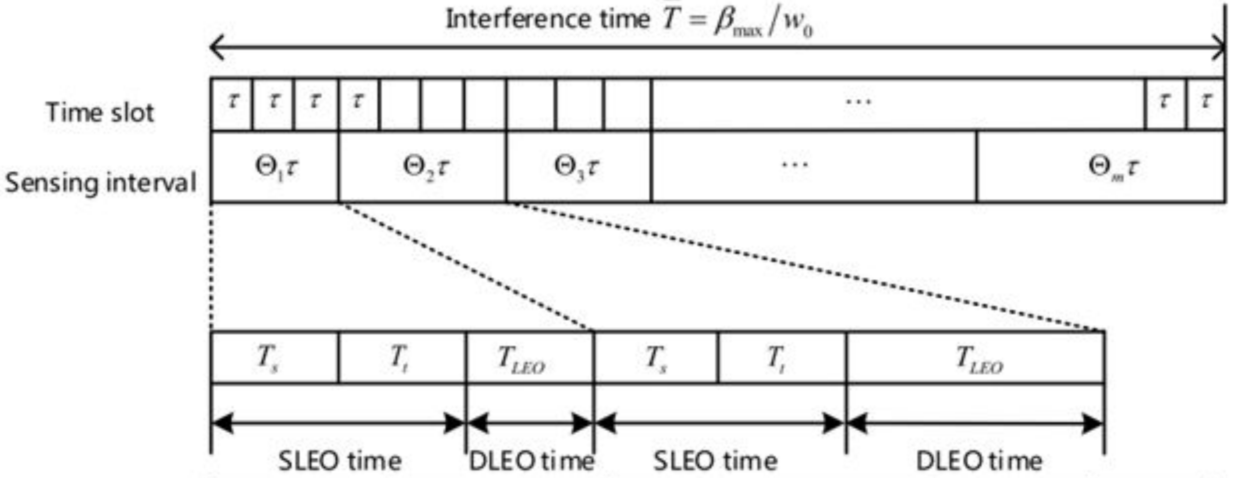
$$v_1 = T_{LEO} - E(X^0_1)\tau$$
$$v_2 = \boxed{E(X^0_1)}\tau$$
$$v_3 = \boxed{E(X^1_1)}\tau - T_s - T_t$$
$$v_4 = \Theta\tau - E(X^1_1)\tau$$

$$\boxed{U_{00}} = P(H_0)(1 - Pf_{S1})$$
$$\boxed{U_{01}} = P(H_0)(Pf_{S1})$$
$$\boxed{U_{10}} = P(H_1)(1 - Pd_{S1})$$
$$\boxed{U_{11}} = P(H_1)(Pd_{S1})$$

<Average Throughput of DLEO>

$$\overline{C_{E3\to S3}} = U_{00}C_{00} + U_{01}C_{01} + U_{10}C_{10} + U_{11}C_{11}$$

Problem 2 : Satellite-Satellite Network



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Busy: $P(H_1)$	Busy:Pd_{S1}	v_3	v_4	0	P^1_{E3}

$$\underset{P^0_{E3}, P^1_{E3}, \Theta, T_s}{\text{maximize}} \ \boxed{C_{E3\to S3}}$$

$$\begin{aligned}
\text{suject to C1:} \quad & \overline{C_{E3\to S3}} \geq C^{\min}_{E3\to S3} \\
\text{C2:} \quad & 0 \leq P^i_{E3} \leq P^{\max}_{E3}, i = 0, 1 \\
\text{C3:} \quad & 0 \leq \overline{I_{S2}} \leq I^{\max}_{S2} \\
\text{C4:} \quad & P^1_{E3} G_{S3}\{\beta\} \leq I^{\max}_{S2} \\
\text{C5:} \quad & T_{\min} \leq T_s \leq \Theta\tau - T_t \\
\text{C6:} \quad & 1 \leq \Theta \leq \Theta_{\max}
\end{aligned}$$

Constraint :

C1 : DLEO system be greater than the target threshold

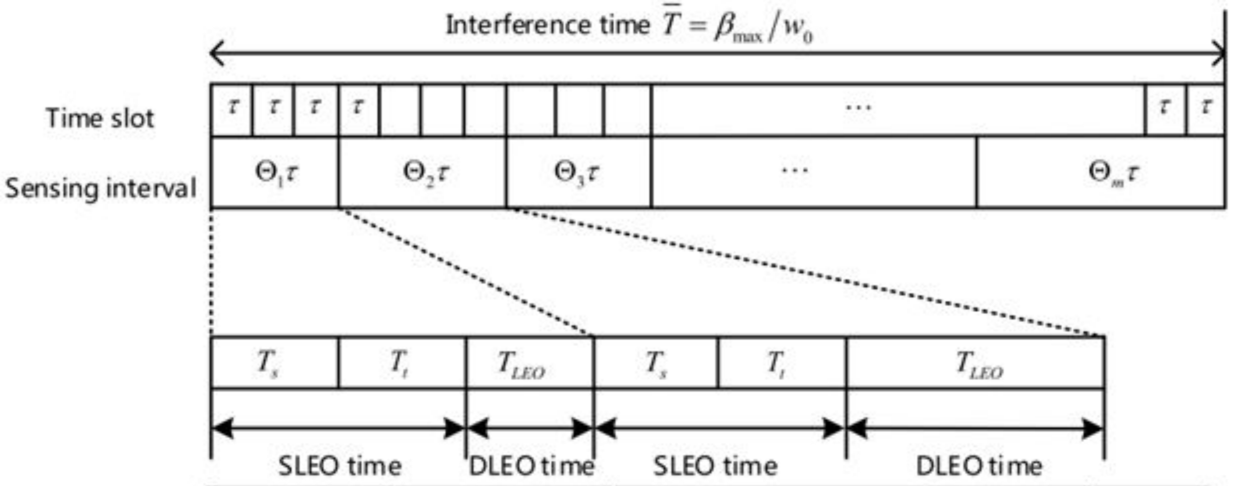
C2 : Total Transmit power of DLEO be less than maximum power

C3 & C4 : Average interference and instantaneous interference less than a predefined threshold max(I_s2)

C5 & C6 : sensing time limitation

$$\boxed{\overline{I_{S2}}} = \frac{1}{\Theta\tau}\left[\begin{pmatrix} U_{00}v_2P^0_{E3} + U_{01}v_2P^1_{E3} \\ +U_{10}v_3P^0_{E3} + U_{11}v_3P^1_{E3} \end{pmatrix} G_{S3}\{\beta\}\right] \quad \boxed{G_{S3}\{\beta\}} = G^t_{E3\to S2}(\theta_4) G^r_{S2\to E3}(\theta_5)\left(\frac{c}{4\pi f d_{S2\to E3}}\right)^2$$

Problem 2 : Satellite-Satellite Network



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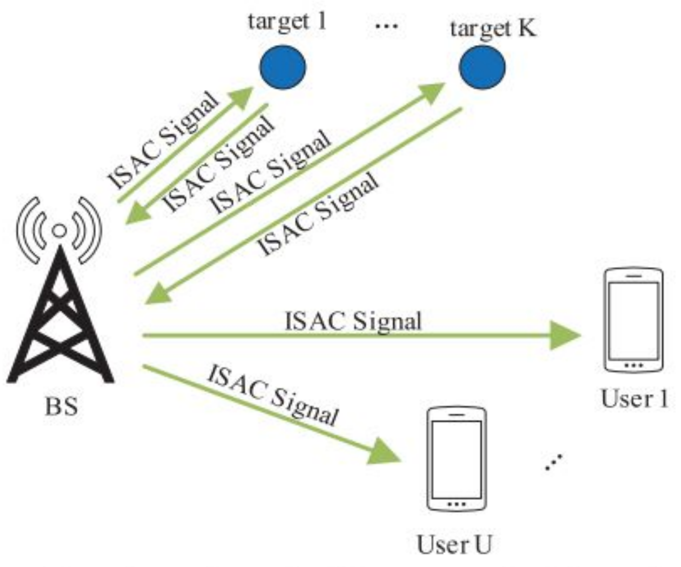
Busy: $P(H_1)$	Busy:Pd_{S1}	v_3	v_4	0	P^1_{E3}

- Conclusion and Challenges
  - It lead LEO satellite systems to <u>maximize average</u> throughput
  - SLEO access to GEO which has leftover spectrum or not
  - But if SLEO get wrong state of GEO, it can make more interference.
  - DLEO – SLEO – GEO network consecutively communicated for getting information (Latency problem)

Problem 3 : Integrated Sensing and Communication



(c) Broadcast channel with mono-static BS sensing.

- Background of Integrated Sensing And Communication (ISAC)
  - Radar & Comms go to higher bands, large antenna arrays and miniaturization
  - Radar & Comms become similar in hardware architecture, channel characteristics, as well as in signal processing
  - Many emerging B5G/6G and IoT applications require ISAC designs
- ISAC
  - ISAC refers to a design paradigm and corresponding enabling technologies in which sensing and comms systems are integrated to efficiently utilize congested resources, and even to pursue mutual benefits

Problem 3 : Integrated Sensing and Communication

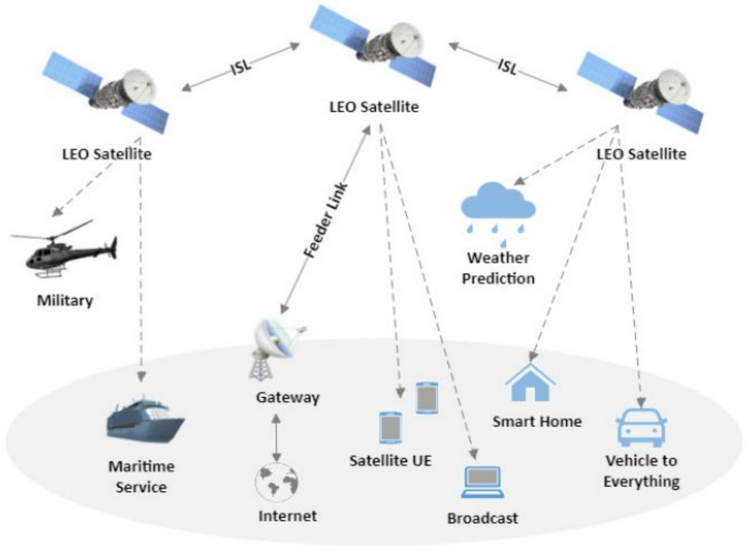
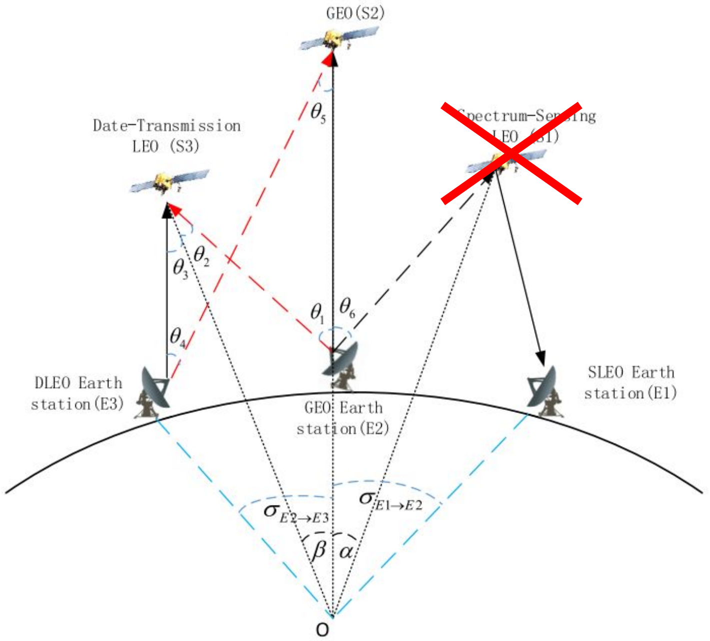


Fig. 1: Model of a joint sensing and communications enabled LEO satellite system.

Integrated Sensing and Communications Enabled Low Earth Orbit Satellite Systems
https://arxiv.org/abs/2304.00941



- Conclusion and Challenges
  - Satellite payload could be more smaller (Hardware is combined to one system) -> Cost Reduction
  - Time delay between sensing and communication is diminished or deleted
  - But Optimization (Interference or Power, etc) of combined system is being more complicated

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Conclusion

- **Problem Setting**
  - Satellite-Terrestrial Network
  - Satellite-Satellite Network
- **Conclusion**
  - We discuss two network and adapting this system to Integrated sensing and communication.
  - Using cognitive radio leads improving data throughput entire system.
  - But we encounter problems at each scenario.

(Time delay for sensing, Optimization in ISAC, efficiency in PCI, DBI in Satellite-Terrestrial Network)

THANK YOU