IOT4EO WORKSHOP

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02.12.2024

AGENDA

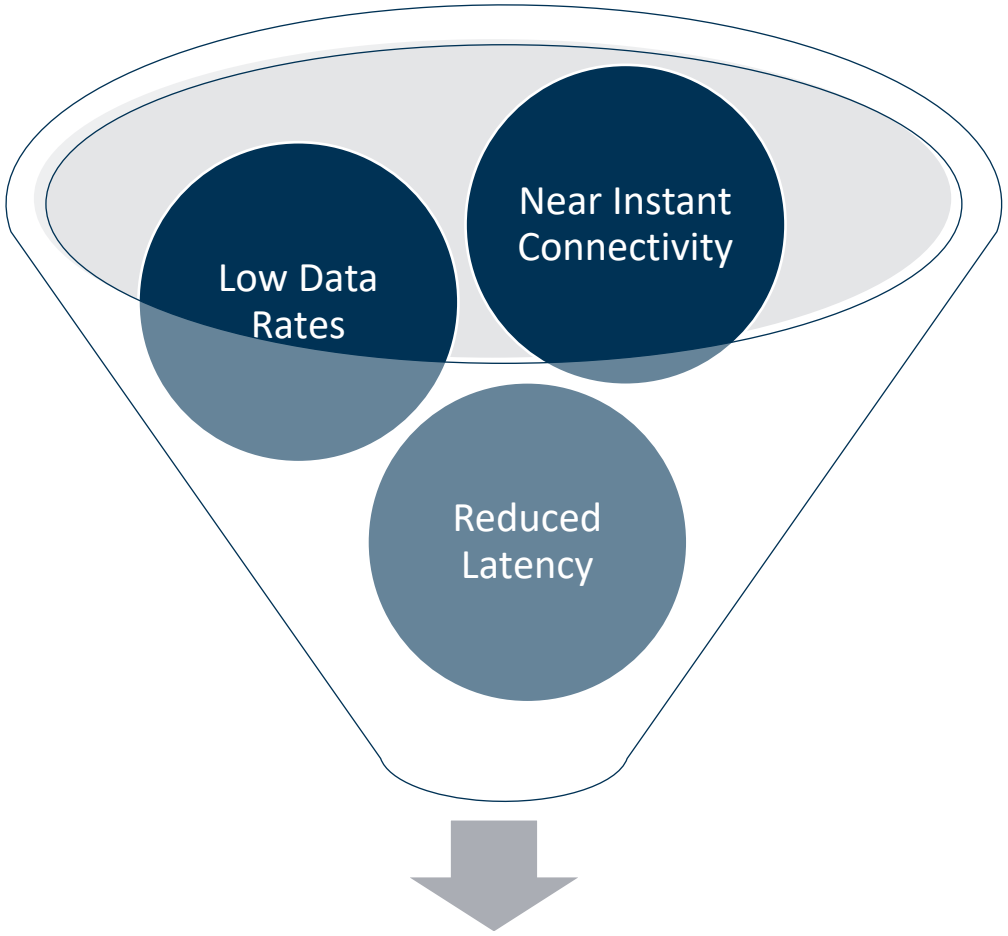
1. General Overview and Study Objectives
2. Frequency & Protocol Selection Trade-Off
3. Service A-1 Solution
4. Service A-2 Solution
5. Service B Solution
6. Assessment of System Requirements & Conclusion

1

GENERAL OVERVIEW AND STUDY OBJECTIVES

GENERAL OVERVIEW AND STUDY OBJECTIVES

OBJECTIVES AND INDUSTRIAL PARTNERS



IoT4EO Network

GENERAL OVERVIEW AND STUDY OBJECTIVES

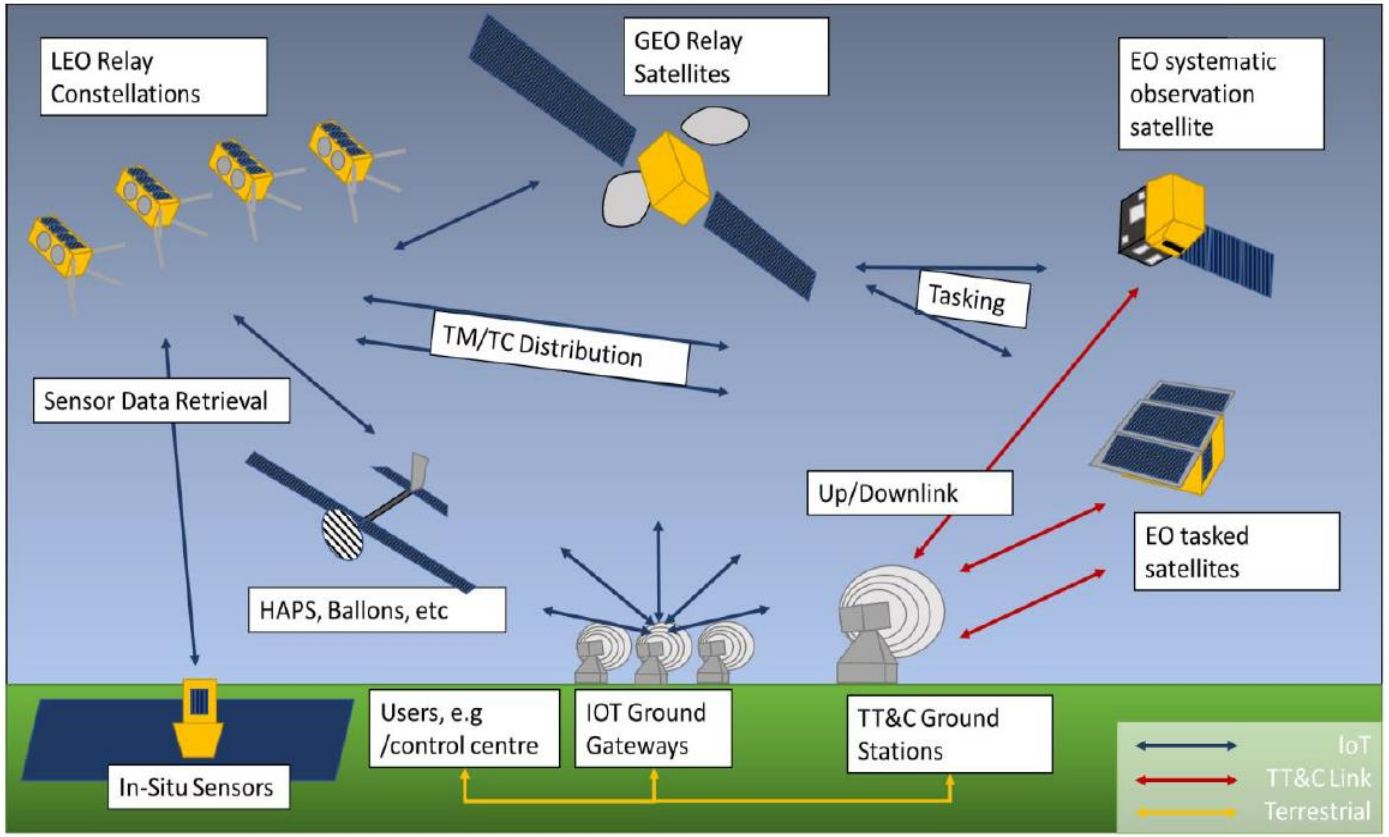
GENERAL OVERVIEW

TM/TC Traffic

- IoT Gateways
  - Direct Link
  - Link via ISL

Collecting in-situ Sensor Datas

- In-Situ Sensors
  - Direct Link



II

FREQUENCY & PROTOCOL SELECTION TRADE-OFF

FREQUENCY SELECTION TRADE-OFF

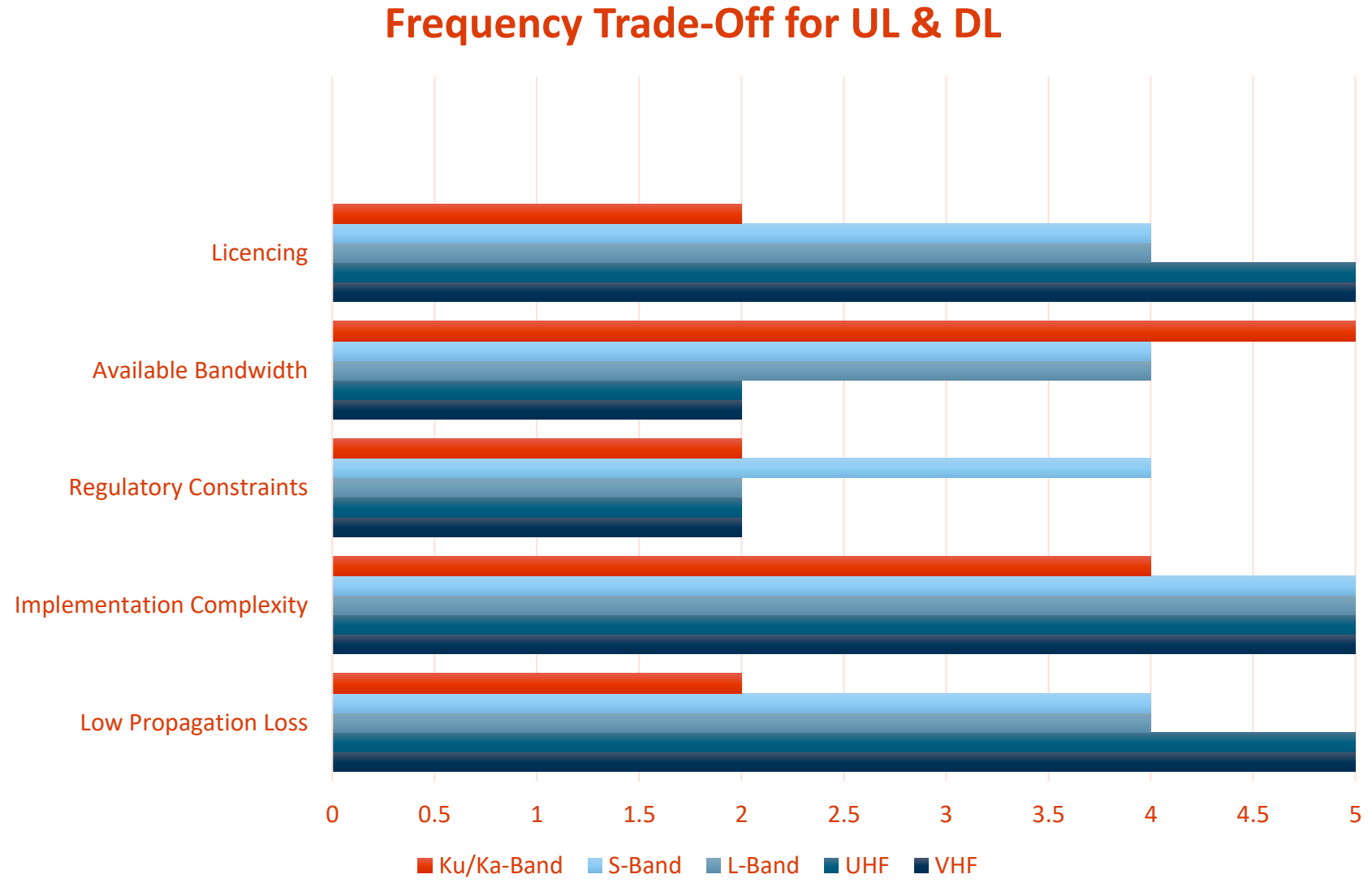
FREQUENCY SELECTION FOR UPLINK & DOWNLINK

VHF	•137-138 MHz for UL, 148-150.5 MHz for DL •Low Atmospheric Loss •Exclusive for NGSO Systems •Low Available Bandwidth •Subject to EPFD limits for DL •Exempt from individual licencing in Europe
UHF	•399.9-400.05 MHz for UL, 400.15-401 MHz for DL •Low Atmospheric Loss •Low Available Bandwidth •Subject to EPFD limits for DL •Exempt from individual licencing in Europe
L-Band	•1610-1675 MHz for UL, 1518-1559 MHz for DL •Moderate Atmospheric Loss •Higher Available Bandwidth w.r.t. VHF and UHF •Individual licencing required
S-Band	•1980-2010 MHz for UL, 2170-2200 MHz & 2483.5-2500 MHz DL •No Emission Limits •Moderate Atmospheric Loss •Higher Available Bandwidth w.r.t. VHF & UHF •Individual licencing required
Ku/Ka-Band	•27.5-30 GHz for UL, 17.7-20.2 GHz for DL •Not optimal for GSL applications due to high propagation losses •High Available Bandwidth •Subject to EPFD limits to protect GSO Systems •Individual licencing required

FREQUENCY SELECTION TRADE-OFF

FREQUENCY SELECTION FOR UPLINK & DOWNLINK

Criterion	Weighting Factor
Low Propagation Loss	0.3
Implementation Complexity	0.2
Regulatory Constraints	0.2
Available Bandwidth	0.2
Licencing	0.1

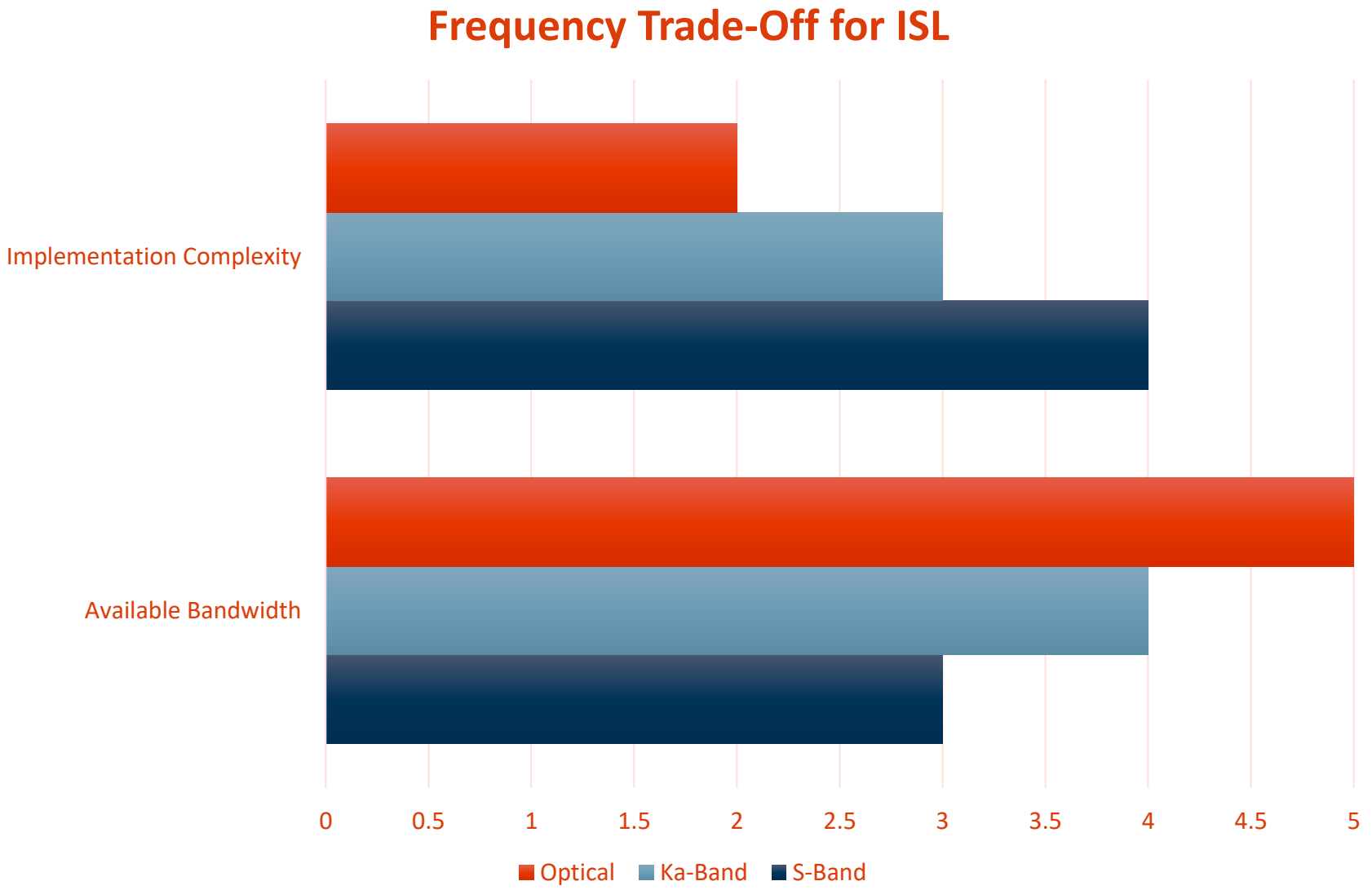


- S-Band is the most convenient.

FREQUENCY SELECTION TRADE-OFF

FREQUENCY SELECTION FOR ISL

Criterion	Weighting Factor
Available Bandwidth	0.5
Implementation Complexity	0.5



- Ka-Band is the most convenient.

PROTOCOL SELECTION TRADE-OFF

PROTOCOL SELECTION FOR UL, DL & ISL

LoRa

- Low Power Consumption
- Wide Coverage
- Interference Robustness
- Scalability
- Flexibility for Hybrid Networks

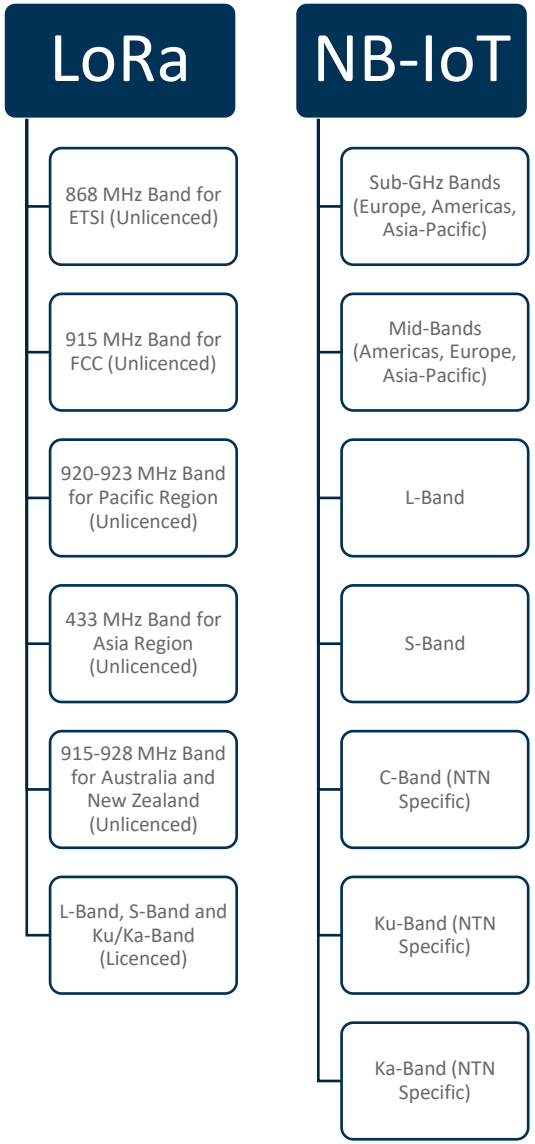
NB-IoT

- Standardization and Global Adoption
- Licensed Spectrum Usage
- Enhanced Link Budget
- IoT Specific Design
- Low Power Consumption

LPWAN Technologies for NTN Communication

PROTOCOL SELECTION TRADE-OFF

PROTOCOL SELECTION FOR UL, DL & ISL

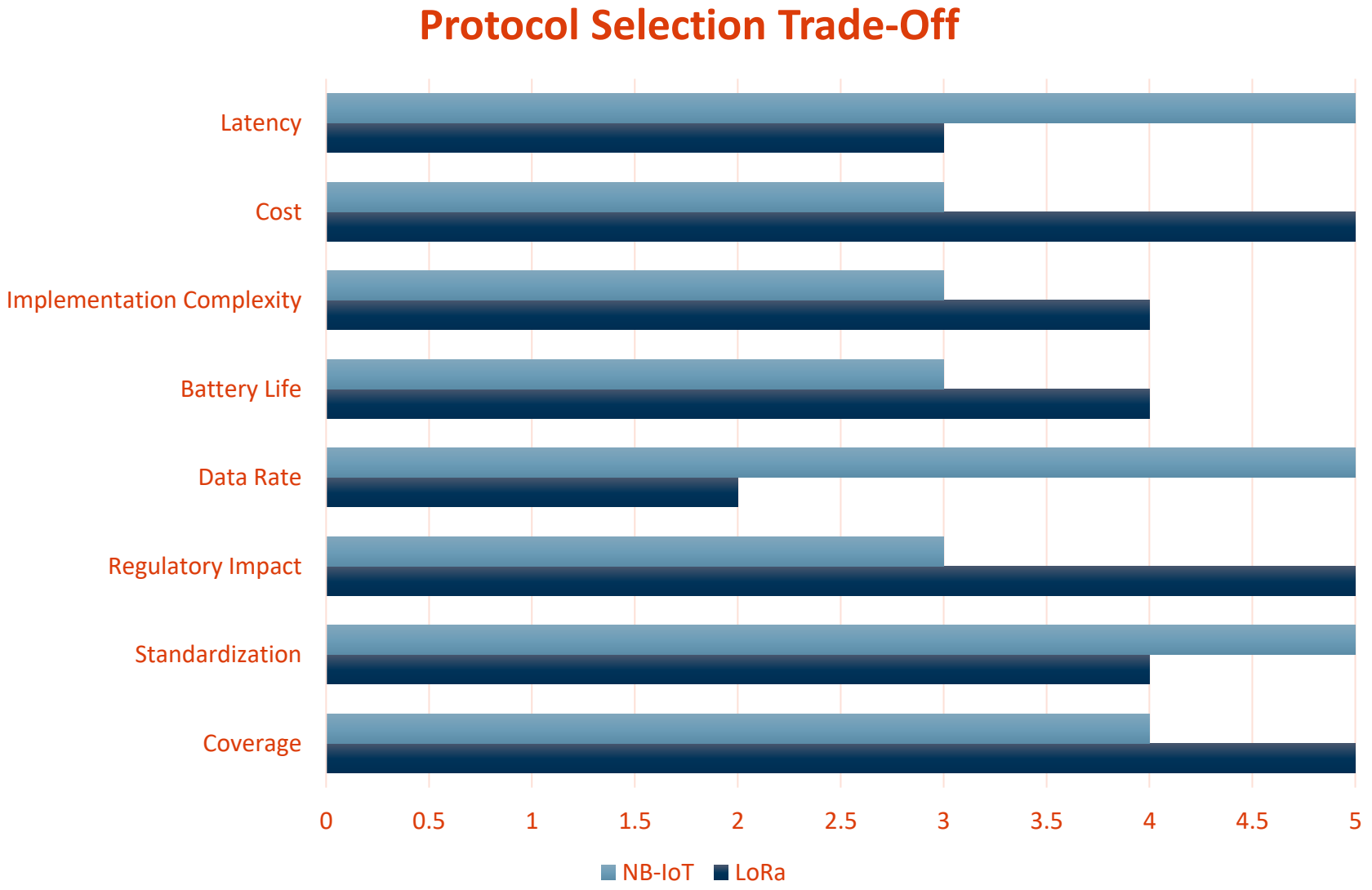


PROTOCOL SELECTION TRADE-OFF

PROTOCOL SELECTION FOR UL, DL & ISL

Criterion	Weighting Factor
Coverage	0.1
Standardization	0.2
Regulatory Impact	0.1
Data Rate	0.1
Battery Life	0.1
Implementation Complexity	0.1
Cost	0.1
Latency	0.2

- NB-IoT is selected.



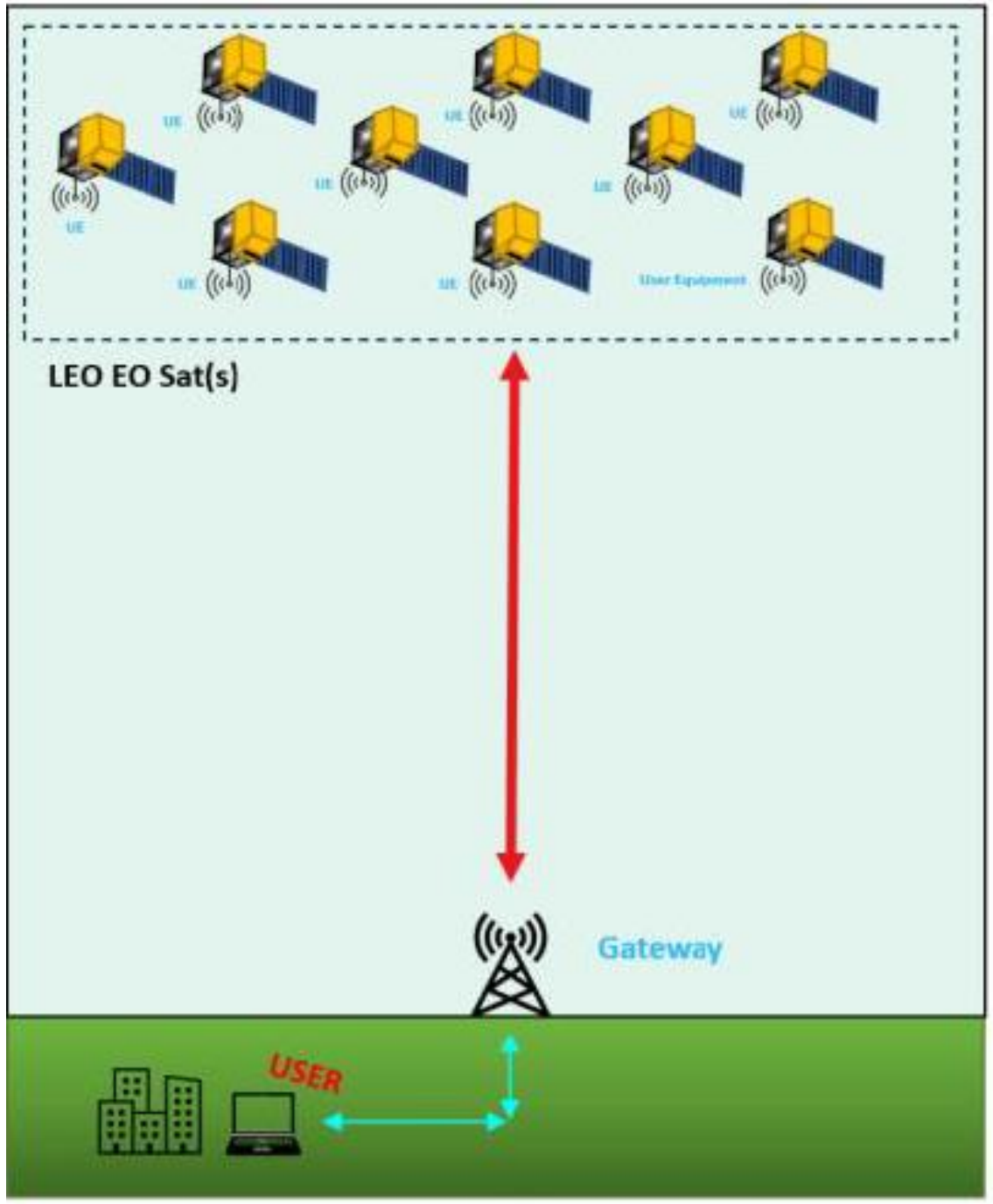
III

SERVICE A-1 SOLUTION

SERVICE A-1 SOLUTION

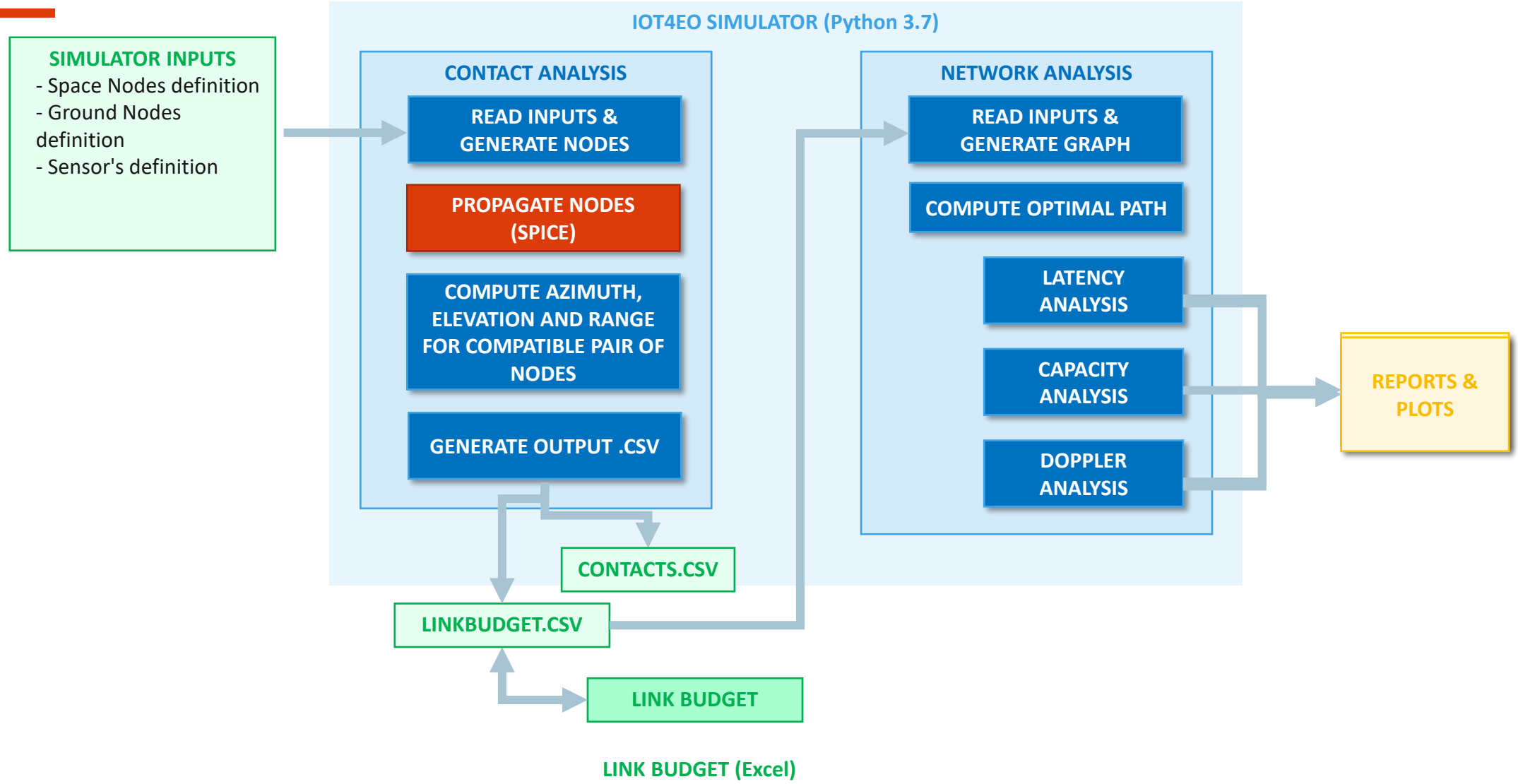
CONOPS ARCHITECTURE

- Direct Link between Gateway-EO
  - Bi-directional
  - TM/TC Extraction
- Mission Inputs
  - S-Band for UL & DL
    - UL: 1995 MHz, DL: 2185 MHz
  - NB-IoT Protocol
    - 200 kHz Channel Bandwidth
  - Minimum Elevation Angle: 10 degrees
  - Number of Gateways: 40-60 (TBC)
  - Satellite Altitude: 400 km
  - Omnidirectional Gateway Antennas



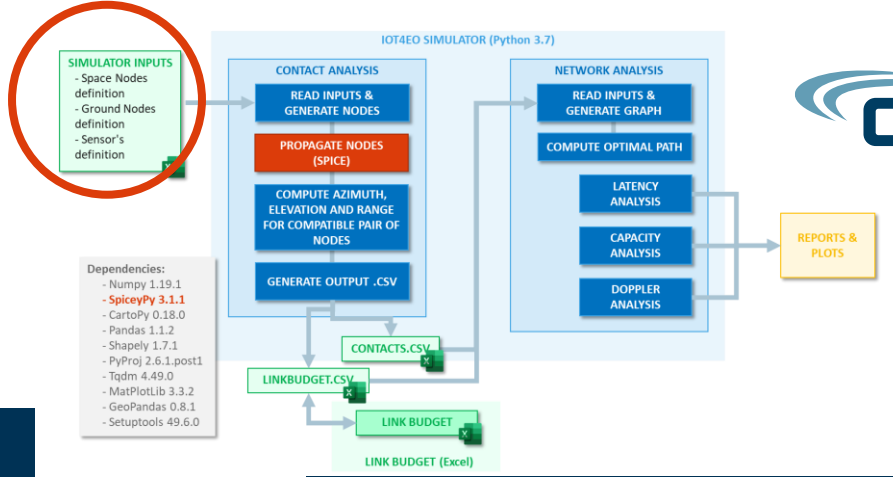
SERVICE A-1 SOLUTION

IOT4EO SIMULATOR



SERVICE A-1 SOLUTION

IOT4EO SIMULATOR



Space Nodes Definition

Definition of both single nodes and constellations (Walker, RAAN distributed, MA distributed, Random).
Nodes are defined using Keplerian elements.

Ground Nodes Definition

Ground Nodes are defined by latitude, longitude and altitude coordinates. Also, it is defined the compatibility of ground-ground connections, and the data rate of on-ground connections.

Sensor Definition

Defines the transmitters attached to the space and ground nodes to perform space-space or space-ground connections. Defined by maximum data rate, FOV angles, azimuth angles and maximum range. Also specifies the compatibility of the transmitters with the created nodes.

7										
8	MEAN ANOMALY DISTRIBUTED	TotalNumSats	-	-	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
9											
10	NO				7073	0	1.7136	1.3904	0	0.0020925	
11	NO				42170	0	0.07798	0.8121	1.2981	2.0317	Transmitter_GEO
12	NO				42172	0	0.0771	0.8543	1.1876	3.3401	Transmitter_GEO
13	NO				42162	0	0.06553	0.6387	1.3846	0.2494	Transmitter_GEO
14	RAAN DISTRIBUTED	10			14203	0	0.00234	1.5875	0	5.3186	Transmitter_MEO, Transmitter_MEOGEO, Transmitter_MEOMEO
15	WALKER STAR	6	66	2	7163	0	1.5708	0	0	0	Transmitter_IR, Transmitter_IR_GEO, Transmitter_IR_INTER
16											

Space Nodes Definition | Ground Nodes Definition | Sensor Definition

SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

	A	B	C	D	E	F	G	H	I	J	K	L
1		Constellation										SENSORS
2	Name	Constellation Type	Con Parameter 1	Con Parameter 2	Con Parameter 3	Orbit Parameter 1	Orbit Parameter 2	Orbit Parameter 3	Orbit Parameter 4	Orbit Parameter 5	Orbit Parameter 6	ATTACHED SENSORS
3		RANDOM	TotalNumSats	-	-	Min Semi-major axis [km]	Max Semi-major axis [km]	Min Eccentricity	Max Eccentricity	Min Inclination [rad]	Max Inclination [rad]	
4		NO	-	-	-	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
5		WALKER DELTA	NumPlanes	TotalNumSats	InterPlanePhaseIncrement	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
6		WALKER STAR	NumPlanes	TotalNumSats	InterPlanePhaseIncrement	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
7		RAAN DISTRIBUTED	TotalNumSats	-	-	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
8		MEAN ANOMALY DISTRIBUTED	TotalNumSats	-	-	Semi-major axis [km]	Eccentricity	Inclination [rad]	RAAN [rad]	Argument of Perigee [rad]	True anomaly at epoch [rad]	
9												
10	SENTINEL_1	NO				7073	0	1.7136	1.3904	0	0.0020925	
11	INMARSAT_4F1	NO				42170	0	0.07798	0.8121	1.2981	2.0317	Transmitter_GEO
12	INMARSAT_4F2	NO				42172	0	0.0771	0.8543	1.1876	3.3401	Transmitter_GEO
13	INMARSAT_4F3	NO				42162	0	0.06553	0.6387	1.3846	0.2494	Transmitter_GEO
14	O3B	RAAN DISTRIBUTED	10			14203	0	0.00234	1.5875	0	5.3186	Transmitter_MEO, Transmitter_MEOGEO, Transmitter_MEOMEO
15	IRIDIUM	WALKER STAR	6	66	2	7163	0	1.5708	0	0	0	Transmitter_IR, Transmitter_IR_GEO, Transmitter_IR_INTER
16												

Space Nodes Definition | Ground Nodes Definition | Sensor Definition

SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

	A	B	C	D	E	F	G	H
1	Definition		Location			SENSORS	COMPATIBLE GROUND TYPE & DATA RATE	
2								
3	Name	Type	Latitude [deg]	Longitude [deg]	Altitude [km]	SENSORS	Compatibility	MAX RATE [kbps]
4	FOS	OS	50	9	0	Transmitter_FOS	Facility	50000
5	GROUNDSTATION_0	Facility_Asia	19	-155	0	Transmitter_GS	Facility_Asia, OS	50000
6	GROUNDSTATION_1	Facility_NAmerica	40	-73	0	Transmitter_GS	Facility_NAmerica, OS	50000
7	GROUNDSTATION_2	Facility_SAmerica	-12	-77	0	Transmitter_GS	Facility_SAmerica, OS	50000
8	GROUNDSTATION_3	Facility_SAmerica	-23	-46	0	Transmitter_GS	Facility_SAmerica, OS	50000
9	GROUNDSTATION_4	Facility_Europe	38	-9	0	Transmitter_GS	Facility_Europe, OS	50000
10	GROUNDSTATION_5	Facility_Europe	37	22	0	Transmitter_GS	Facility_Europe, OS	50000
11	GROUNDSTATION_6	Facility_Asia	24	66	0	Transmitter_GS	Facility_Asia, OS	50000
12	GROUNDSTATION_7	Facility_Oceania	-31	115	0	Transmitter_GS	Facility_Oceania, OS	50000
13	GROUNDSTATION_8	Facility_Oceania	-32	148	0	Transmitter_GS	Facility_Oceania, OS	50000
14								
15								

Space Nodes Definition | Ground Nodes Definition | Sensor Definition

SERVICE A-1 SOLUTION

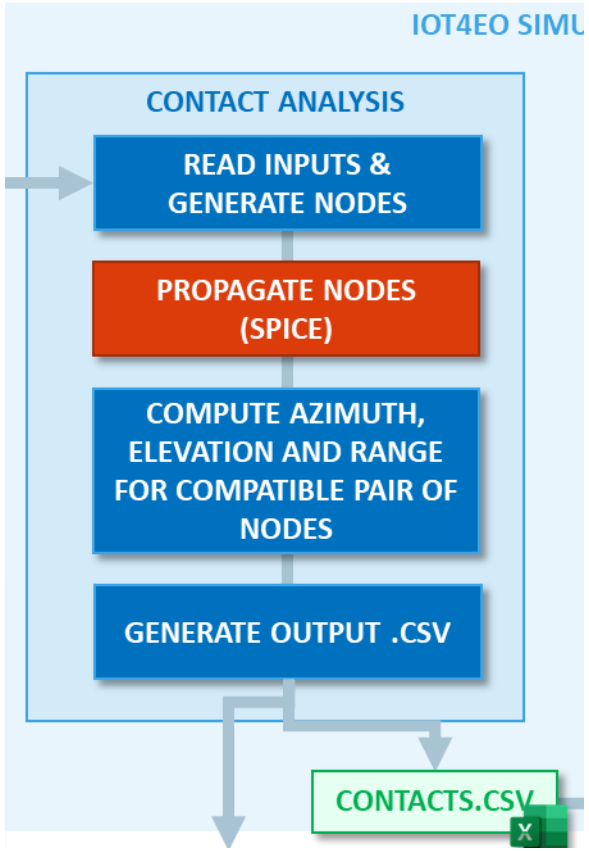
IOT4EO SIMULATOR

	A	B	C	D	E	F	G	H
1	Sensor Definition			Geometry definition				
2	Name	Receiver Type Compatibility	Maximum data rate [kbps]	Inner half fov [deg]	Outer half fov [deg]	Min Azimuth angle [deg]	Max Azimuth angle [deg]	Maximum Range [km]
6	Transmitter_FOS	SENTINEL	50000	0.0	85.0	0.0	360.0	200000
7	Transmitter_GS	INMARSAT, O3B	50000	0.0	90.0	0.0	360.0	200000
8	Transmitter_GEO	FOS, GROUNDSTATION, SENTINEL, IRIDIUM	100000	0.0	9.0	0.0	360.0	40000
9	Transmitter_MEO	FOS, GROUNDSTATION, SENTINEL, IRIDIUM	100000	0.0	26.5	0.0	360.0	40000
10	Transmitter_MEOGEO	INMARSAT	100000	135.0	180.0	0.0	360.0	40000
11	Transmitter_MEOMEO	O3B	100000	0.0	180.0	0.0	360.0	10000
12	Transmitter_IR	FOS, SENTINEL	100000	0.0	180.0	0.0	360.0	4000
13	Transmitter_IR_GEO	INMARSAT	100000	135.0	180.0	0.0	360.0	40000
14	Transmitter_IR_INTER	IRIDIUM	100000	0.0	90.0	0.0	360.0	4500
15								

Space Nodes Definition | Ground Nodes Definition | **Sensor Definition**

SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

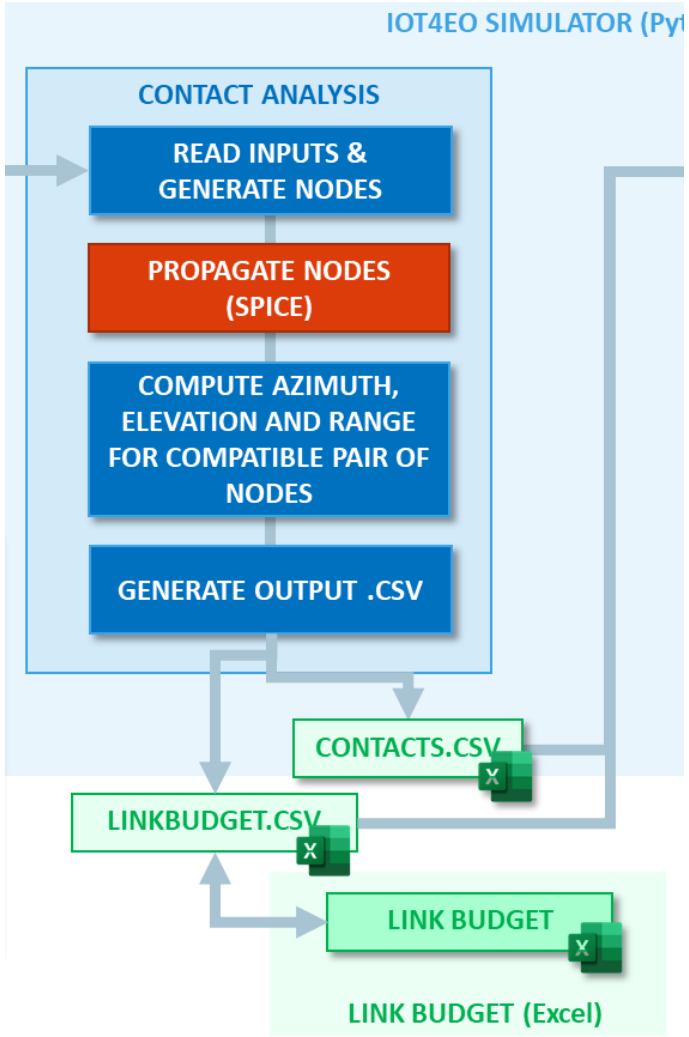


- **Inputs in the code:**
  - Start date
  - Duration
  - Time step of scenario
  - File paths to the inputs and output .csv

- **Output CONTACTS.csv file:**

SERVICE A-1 SOLUTION

IOT4EO SIMULATOR



UNDER DEVELOPMENT

Inputs required from contact analysis included in **LINKBUDGET.csv**:

- Elevation
- Range
- Node altitudes

	A	B			
1	Satellite/INMARSAT_4F1/Transmitter_GEO				
2	Elevation_deg	Range_km	Altitude_Transmitter_km	Altitude_Receiver_km	Data_rate_kbps
3	2.163347576	35427.27531			
4	3.872402864	35684.16108			
5	5.581458152	36181.70418			
6	7.290513441	37015.58143			
7	8.999568729	38497.65944			
8	Satellite/INMARSAT_4F2/Transmitter_GEO,Satellite/EO_0				
9	Elevation_deg	Range_km	Altitude_Transmitter_km	Altitude_Receiver_km	Data_rate_kbps
10	2.163347576	35427.27531			
11	3.872402864	35684.16108			
12	5.581458152	36181.70418			
13	7.290513441	37015.58143			
14	8.999568729	38497.65944			

6	Ground Station Parameters	Unit	Value
7	Latitude	°	34.052
8	Longitude	°	-118.243

25	MEO Relay Satellite Parameters	Unit	Value
26	Altitude	km	8000

Output from Link Budget:

- Data rate for each pair of compatible nodes and elevation value

65	Link Budget		
66	Parameters	Unit	Value
67	Required Eb/No	dB/Hz	9.7
68	Effective Coding Rate	N/A	3.2
69	Spectral Efficiency	bit/s/Hz	0.1878005
70	Required C/N	dB	12.185391
71	Link Margin	dB	5.8249086
72	Achieved Throughput	kbps	38.461538

SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

Latency inputs:

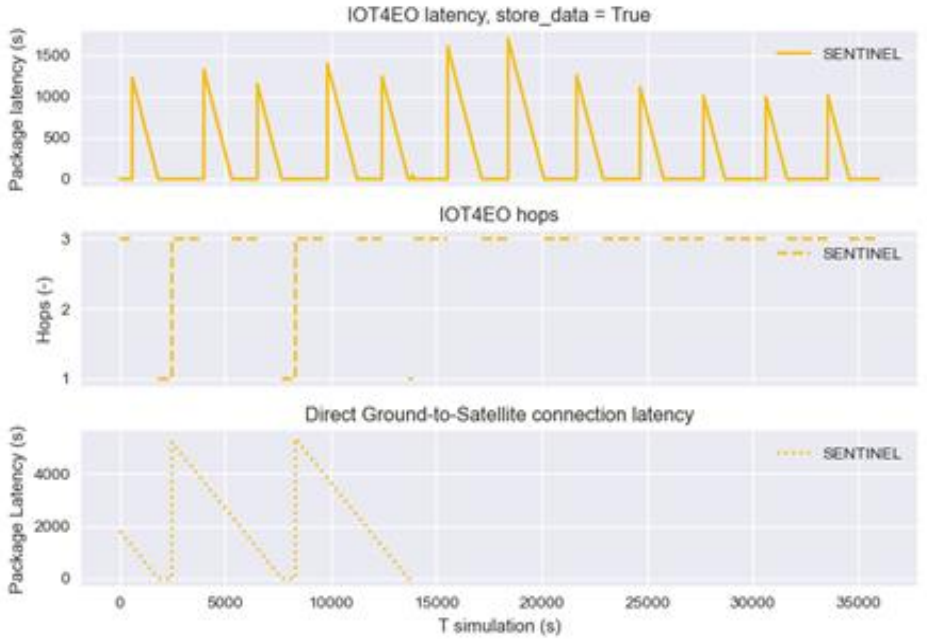
- Starting/Transmitter node
- End node(s)
- Data packet size

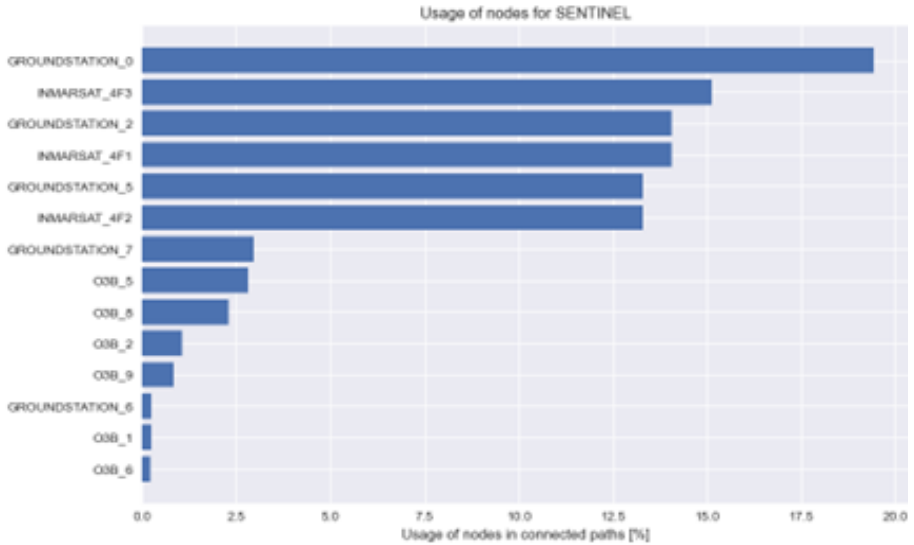
```
start_node = 'FOS'
end_name_lst = ['SENTINEL']

lim = 0          # Stop computation
data = 6000      # Data Packet size
store_data = True
```

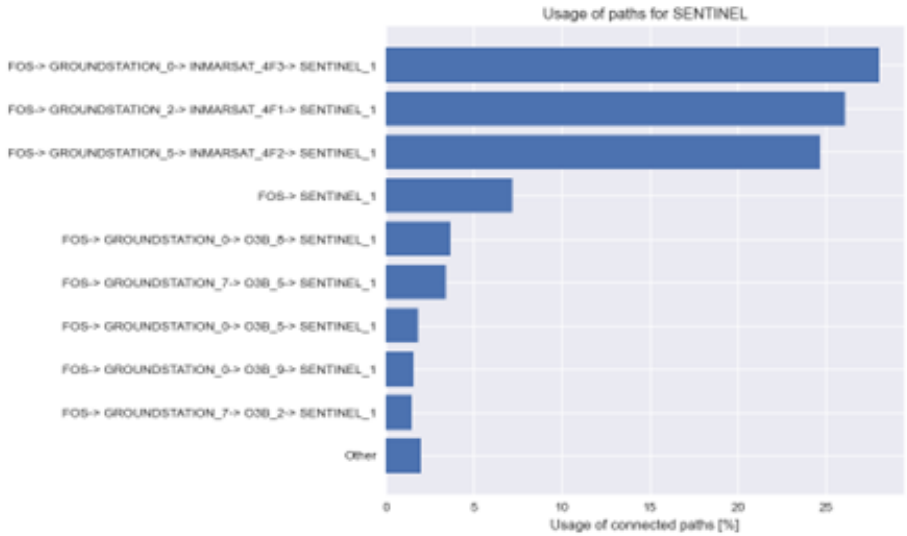
Using Dijkstra's algorithm , the shortest path is found from the transmitter to the end node(s) via the Graph object.

Output:

- Latency over time
- Node usage
- Path usage







SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

Capacity analysis can be performed to determine the network capacity when transmitting data from one station to many nodes at the same time. (e.g, send 100 unique packages to 100 EO s/c from 1 ground station)

Inputs:

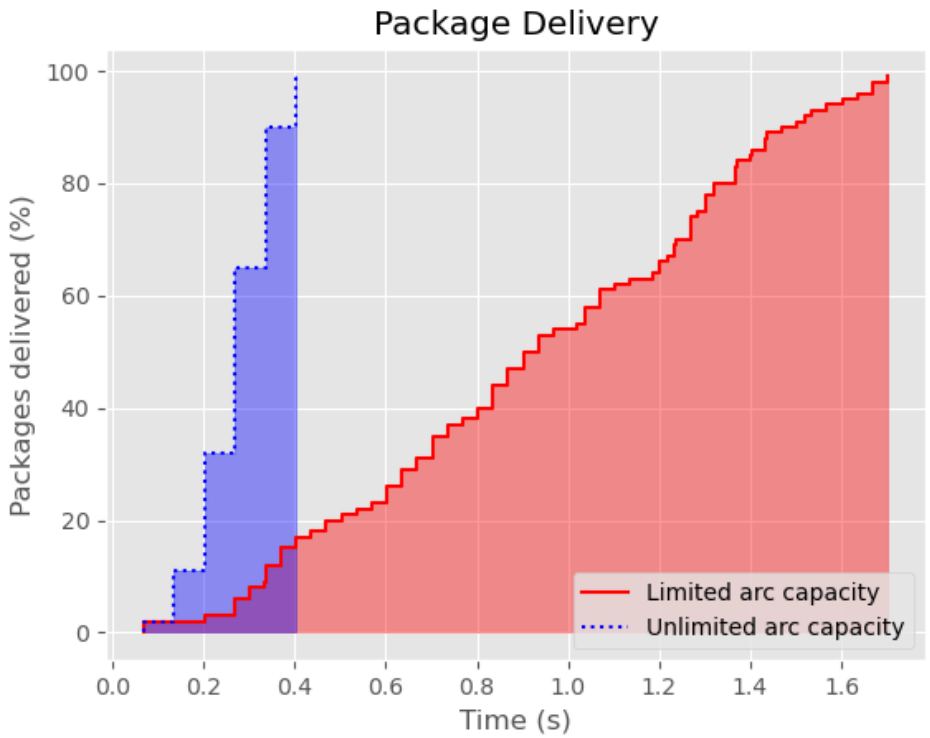
- Starting/Transmitter node
- End node(s) (constellation name)
- Data packet size
- Limitation definition (arc capability limit)

Again, using Dijkstra's algorithm the shortest routes through the graph are found. However, this time the arc usage is also stored.

Output:

- Network capacity

```
start_node = 'FOS'
end_node = 'EO'
data = 6000          # Data packet size [kb]
```



SERVICE A-1 SOLUTION

IOT4EO SIMULATOR

This analysis results in the Doppler distribution for all arcs, and the Doppler evolution for the most limiting arc.

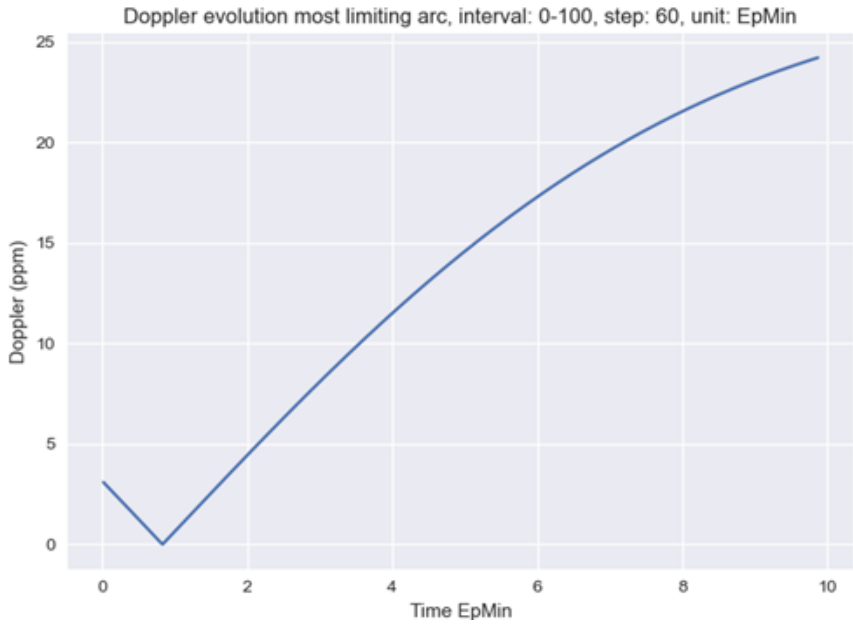
Inputs:

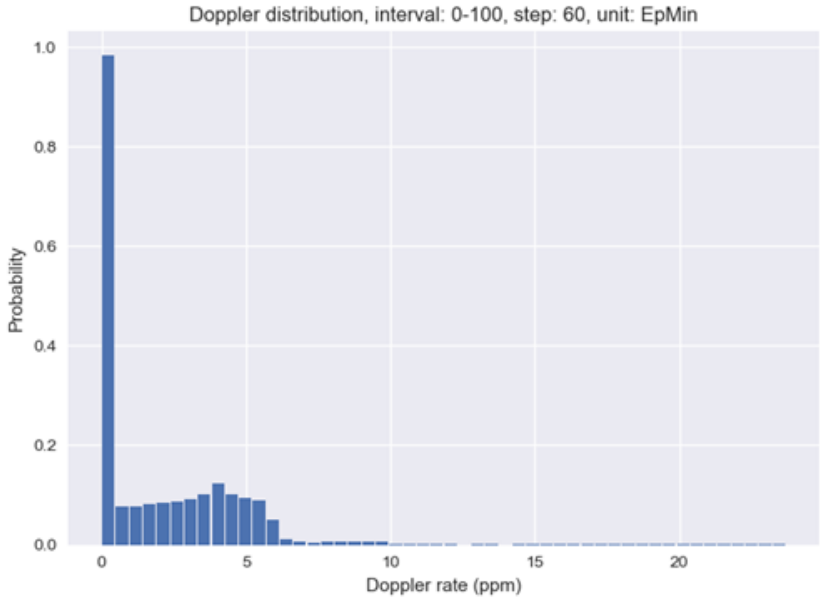
- Start, stop and step for the to be analysed interval
- Start, stop and step times

The function computes the rate of change of the range, which is then transformed to the Doppler outputs.

Outputs:

- Doppler distribution
- Doppler evolution of limiting arc





SERVICE A-1 SOLUTION

LINK BUDGET

	Gateway Antenna Gain	Gateway EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	EO Satellite Antenna Gain @Boresight	EO Satellite G/T	C/N	Link Margin
Uplink	0dBi	20 dBm	10	400 km	1439 km	139.6 dB	140.1 dB	-120.22 dBm	5.69 dBi	-19.61 dB/K	2.17 dB	0.48 dB

	EO Satellite Antenna Gain @Boresight	EO Satellite EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	Gateway Antenna Gain	Gateway G/T	C/N	Link Margin
Downlink	6.68 dBi	12.81 dBW	10	400 km	1439 km	140.41 dB	141 dB	-98.102 dBm	0dBi	-28 dB/K	19.347 dB	4.78

SERVICE A-1 SOLUTION

RESULTS

- <10 minutes

- >2 kbps with 0.48 dB margin for UL
- >23 kbps with 4.78 dB margin for DL

IV

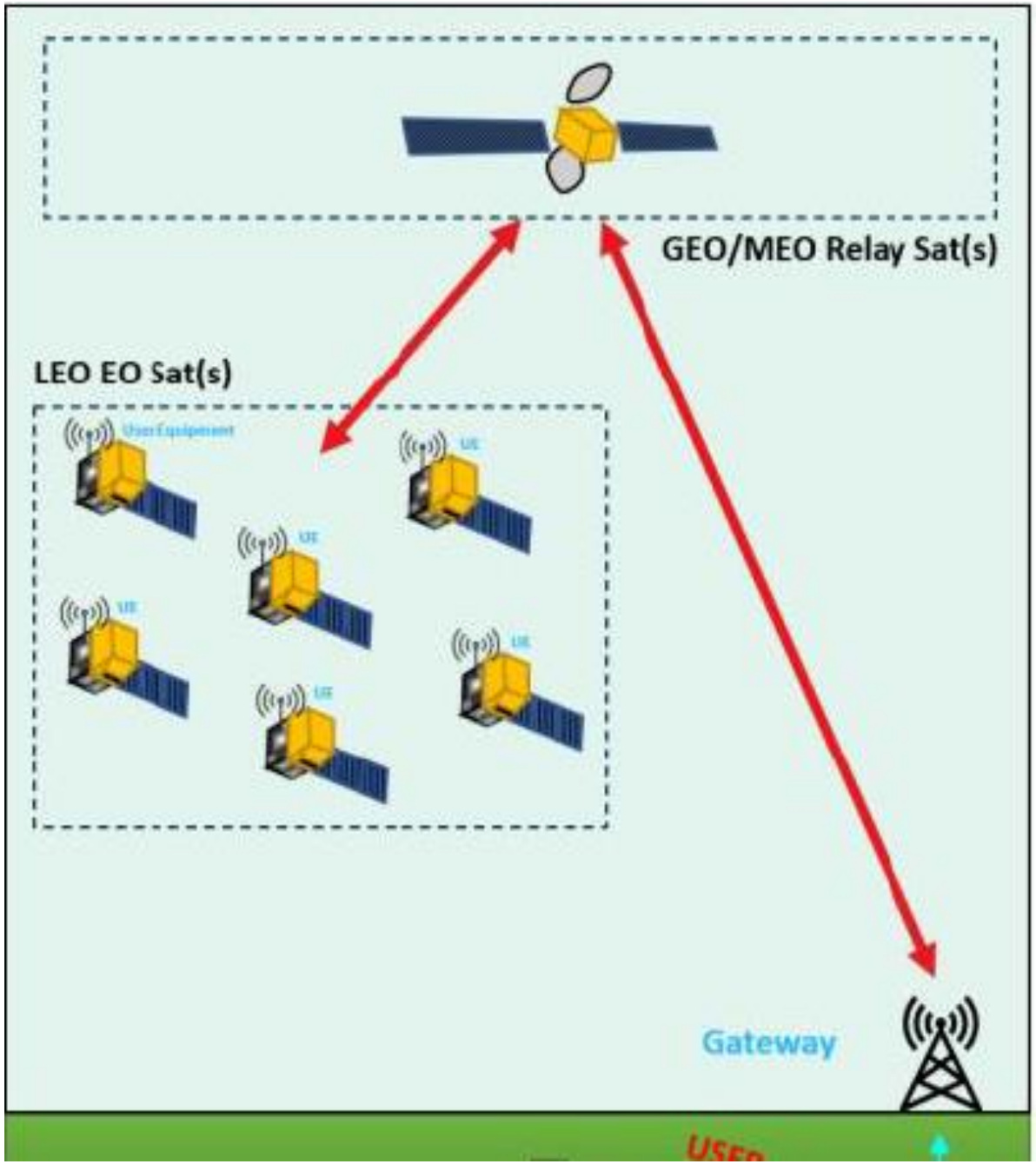
SERVICE A-2 SOLUTION

SERVICE A-2 SOLUTION

CONOPS ARCHITECTURE

- Connection between Gateway-EO satellites via ISL
  - Bi-directional
  - TM/TC Extraction

- Mission Inputs
  - S-Band for UL & DL)
    - UL: 1995 MHz, DL: 2185 MHz
  - Ka-Band for ISL (Add exact frequencies)
    - 22500 MHz
  - NB-IoT Protocol
    - 200 kHz Channel Bandwidth
  - Minimum Elevation Angle: 10 degrees
  - Number of Gateways: 40-60 TBC
  - Omnidirectional Gateway Antennas
  - Satellite Altitudes:
    - GEO: 35786 km
    - MEO: 8000 km
    - EO: 400 km



SERVICE A-2 SOLUTION

LINK BUDGET – MEO RELAY

	Gateway Antenna Gain	Gateway EIRP	Elevation Angle	MEO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	MEO Satellite Antenna Gain @Boresight	MEO Satellite G/T	C/N	Link Margin
Uplink	0 dBi	20 dBm	10	8000 km	11825 km	157.91 dB	158.71 dB	-138.71 dBm	26.691 dBi	-1.477 dB/K	5.106 dB	4.11 dB

	MEO Satellite Antenna Gain	MEO Satellite EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	EO Satellite Antenna Gain	EO Satellite G/T	C/N	Link Margin
ISL	22.12 dBi	31.36 dBW	10	400 km	11379 km	178.62 dB	178.62 dB	-117.26 dBm	5.225 dBi	-22.988 dB/K	2.75	1.85 dB

SERVICE A-2 SOLUTION

LINK BUDGET – GEO RELAY

	Gateway Antenna Gain	Gateway EIRP	Elevation Angle	GEO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	GEO Satellite Antenna Gain @Boresight	GEO Satellite G/T	C/N	Link Margin
Uplink	0dBi	20 dBm	10	35786 km	40586 km	168.62 dB	170.62 dB	-150.62 dBm	41.02 dBi	13.52 dB/K	5 dB	3.904 dB

	GEO Satellite Antenna Gain	GEO Satellite EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	EO Satellite Antenna Gain	EO Satellite G/T	C/N	Link Margin
ISL	50.33 dBi	58.31 dBW	10 degrees	400 km	40181 km	189.58 dB	189.58 dB	-101.269 dBm	5.225 dBi	-22.988 dB/K	18.75 dB	6.07

SERVICE A-2 SOLUTION

RESULTS

- Near-zero

- Via MEO Relay
  - >2 kbps with 4.11 dB margin for UL
  - >2 kbps with 1.85 dB margin for ISL
- Via GEO Relay
  - > 2kbps with 3.90 dB margin for UL
  - >23 kbps with 6.07 dB margin for ISL

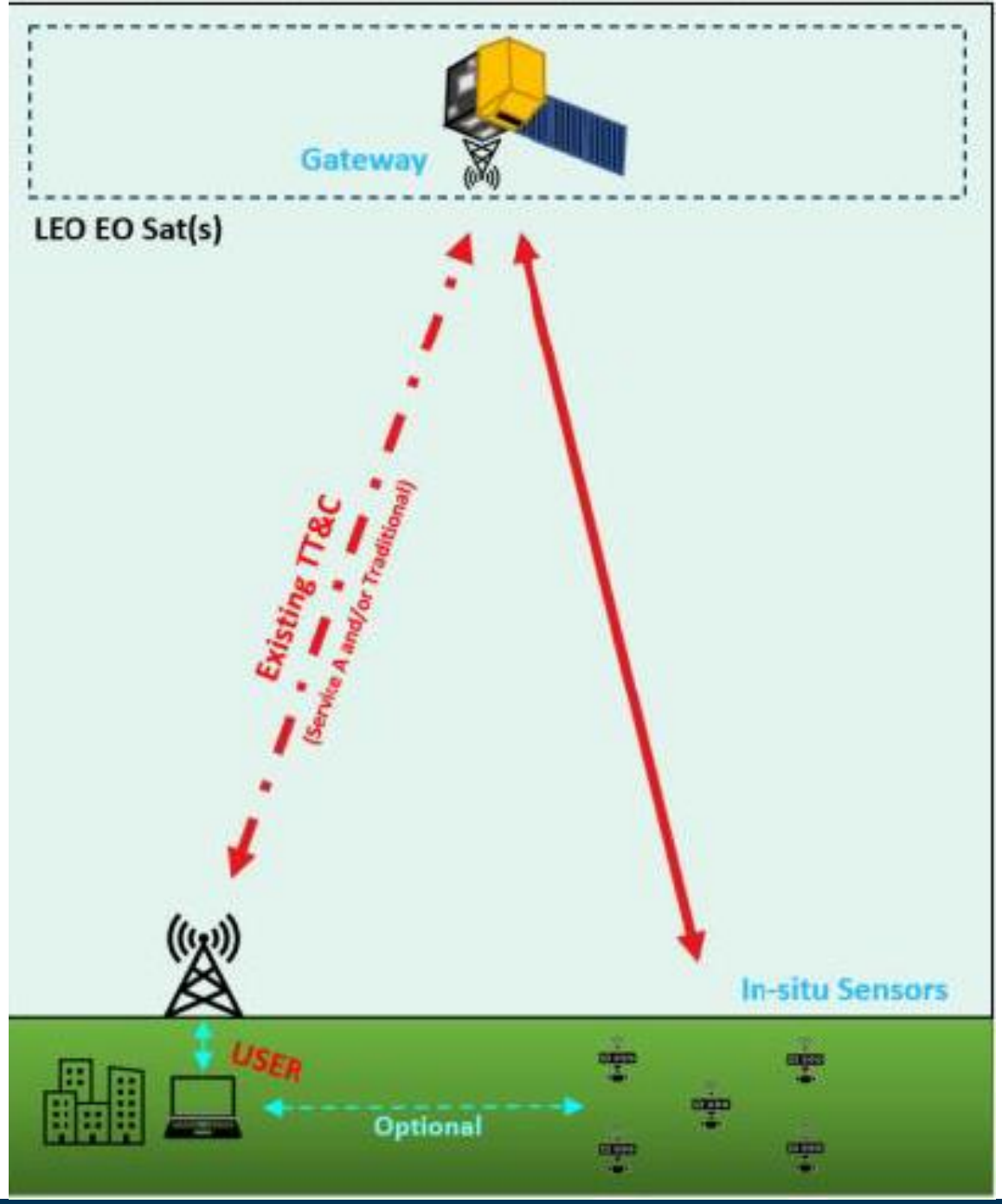
V

SERVICE B SOLUTION

SERVICE B SOLUTION

CONOPS ARCHITECTURE

- Direct link between in-situ sensors and EO satellite
  - Bi-directional
  - Sensor low data collection/transmission
- Mission Inputs
  - S-Band for UL & DL
    - UL: 1995 MHz, DL: 2185 MHz
  - NB-IoT Protocol
    - 200 kHz Channel Bandwidth
  - Minimum Elevation Angle: 10 degrees
  - Satellite Altitude: 400 km



SERVICE B SOLUTION

LINK BUDGET

	In-Situ Sensor EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	EO Satellite Antenna Gain @Boresight	EO Satellite G/T	C/N	Link Margin
Uplink	12 dBm	10 degrees	400 km	1439 km	139.622 dB	140.122 dB	-140.122 dBm	13.67 dBi	-14.84	1.84 dB	0.96 dB

	EO Satellite Antenna Gain @Boresight	EO Satellite EIRP	Elevation Angle	EO Satellite Altitude	Slant Range	FSL	Total Propagation Loss	Received Power	In-Situ Sensor Antenna Gain	C/N	Link Margin
Downlink	14.214 dBi	23.343 dBW	10 degrees	400 km	1439 km	143.166 dB	143.666 dB	-90.323 dBm	-3 dBi	16.93 dB	3.59 dB

SERVICE B SOLUTION

RESULTS

- >2 kbps with 0.96 dB margin for UL
- >23 kbps with 3.59 dB margin for DL

VI

ASSESSMENT OF SYSTEM REQUIREMENTS & CONCLUSION

ASSESSMENT OF SYSTEM REQUIREMENTS

SERVICE A-1

Requirement	Compliance
Data Rate (2 kbps for UL and DL)	✓
Latency (<10 min)	✓
10 or 100 messages per orbit/150 or 1500 messages per day	?
Message lengths (11 Bytes to 1 kB)	?
Minimum Cumulative Data Allowance	TBC according to results of IOT4EO-PRF-130 and IOT4EO-PRF-140
Global Coverage	✓ , Number of Gateways TBC

ASSESSMENT OF SYSTEM REQUIREMENTS

SERVICE A-2

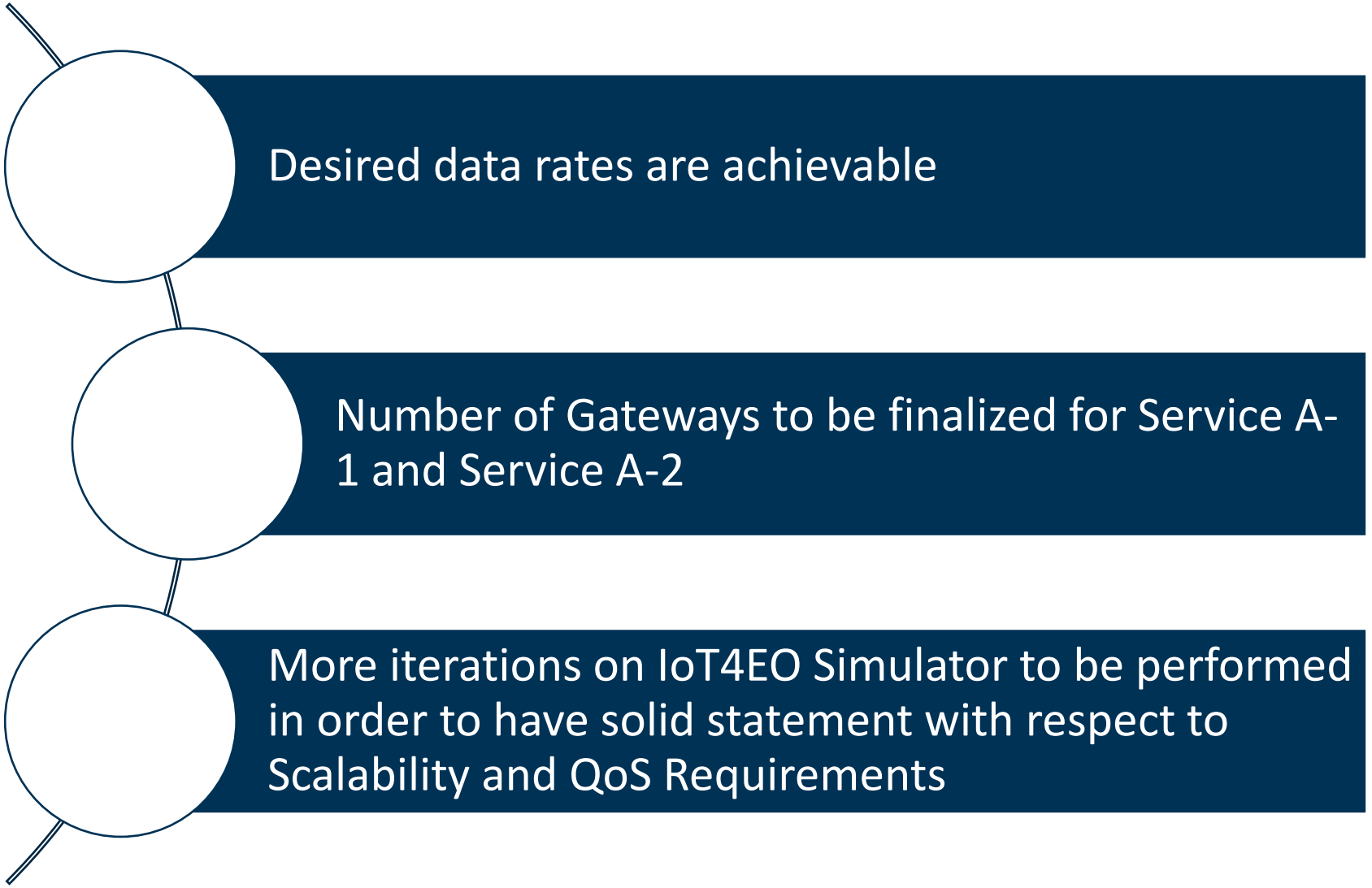
Requirement	Compliance
Data Rate (2 kbps for UL and DL)	✓
Latency (Near-Zero)	✓
10 or 100 messages per orbit/150 or 1500 messages per day	?
Message lengths (11 Bytes to 1 kB)	?
Minimum Cumulative Data Allowance	TBC according to results of IOT4EO-PRF-230 and IOT4EO-PRF-240
Global Coverage	✓ , Number of Gateways TBC

ASSESSMENT OF SYSTEM REQUIREMENTS

SERVICE B

Requirement	Compliance
Data Rate (2 kbps for UL and DL)	✓
2 messages per orbit and 30 messages per day	✓
Message lengths (11 Bytes to 0.2 kB)	?
Minimum Cumulative Data Allowance	TBC according to results of IOT4EO-PRF-130 and IOT4EO-PRF-140
Global Coverage	TBC (sensor deployment on polar areas should analysed in more detail)

CONCLUSION


Desired data rates are achievable
Number of Gateways to be finalized for Service A-1 and Service A-2
More iterations on IoT4EO Simulator to be performed in order to have solid statement with respect to Scalability and QoS Requirements

THANK YOU!