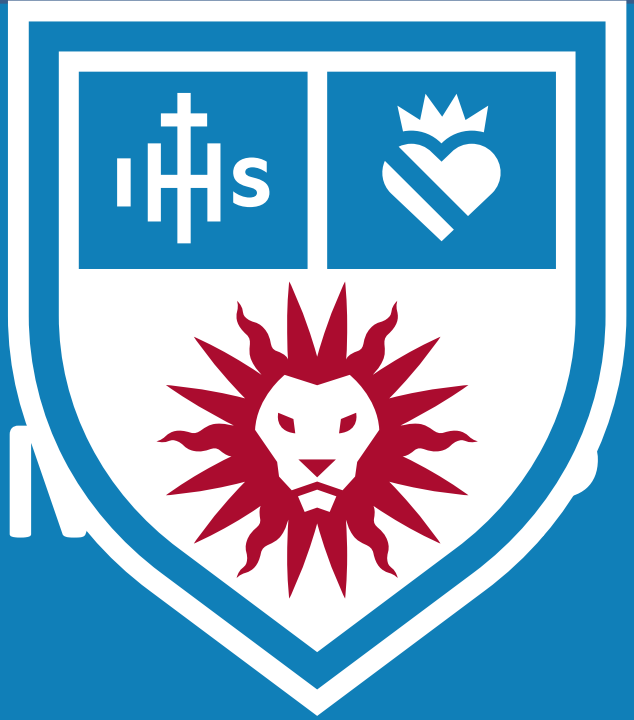

Ian Green & Natalia Cedeño
Loyola Marymount University
Department of Electrical and Computer Engineering
October 26, 2021

Loyola Marymount University

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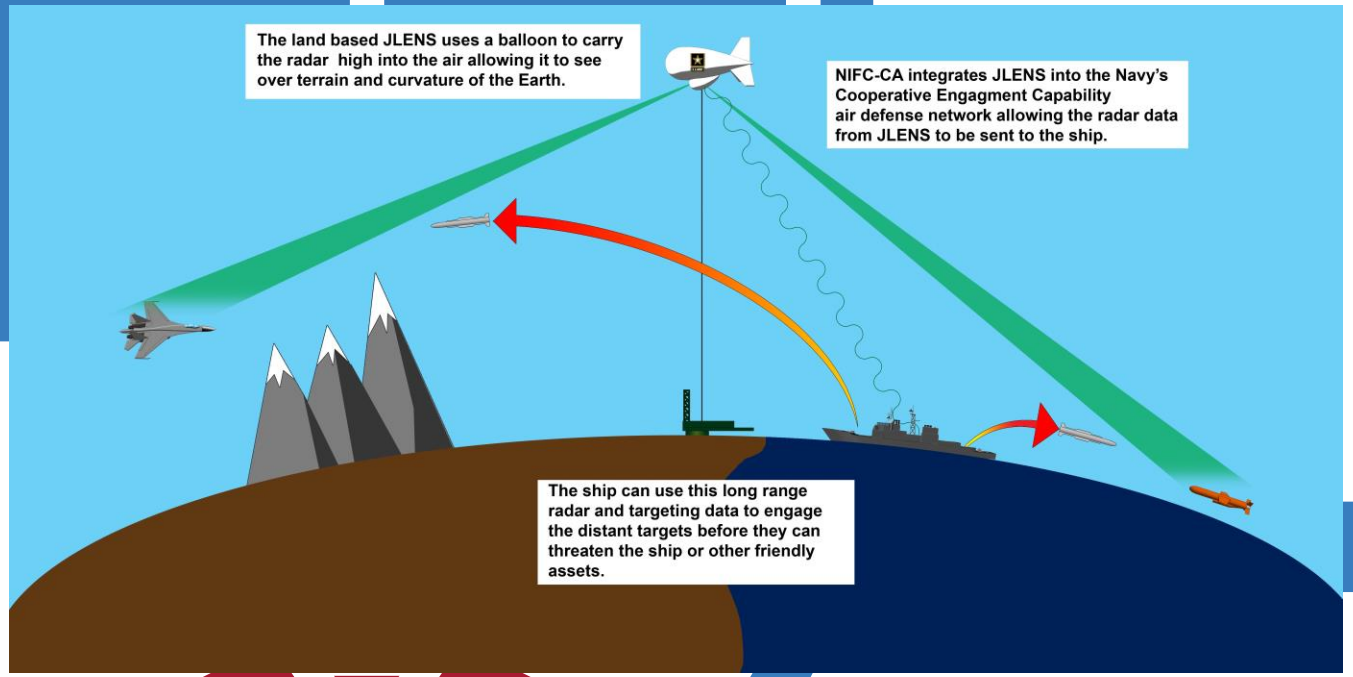
Motivation

What problem are we solving



https://api.army.mil/e2/c/images/2012/11/02/270620/original.jpg

Requirements

Technical Requirements

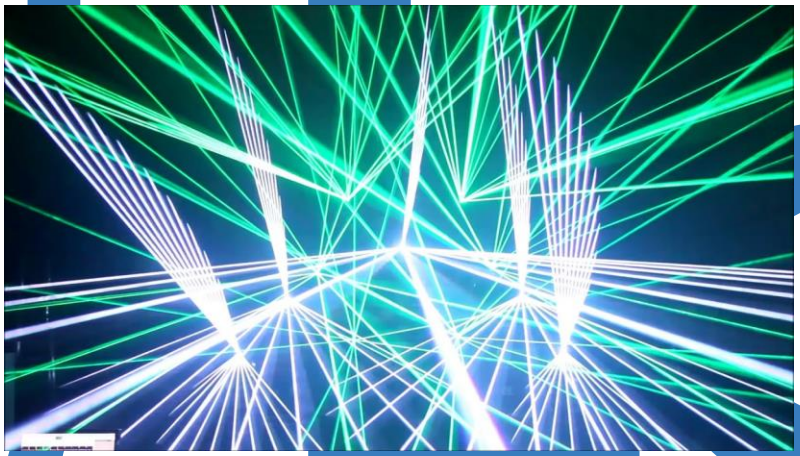
- 1Gbps transmit/receive
- Infrared Wavelength (780nm-1mm)
- 20mm receiver tracking at 100m distance for maximum velocity of 100m/s
- Constant updating of tracking (software)
- Budget of ~$500

https://topcashbuyer.com/wp-content/uploads/500-American-Dollar-Bill-USD-with-President-William-McKinley-on-the-Face-e1574719909489.jpg

Challenges

Main challenges that need to be resolved in the project

- Cheap free space optical
  - Laser generation
  - Signal Generation
    - Computer limits
- Scanning
  - Stability
- Tracking
  - Moving target
  - Moving own-ship

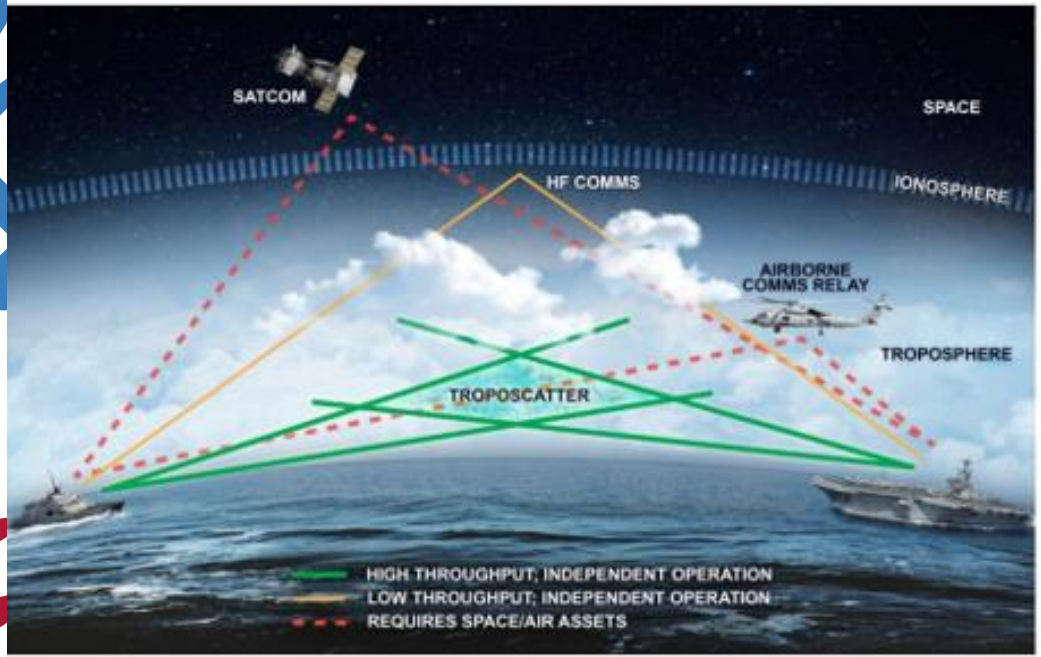


https://i.ytimg.com/vi/Y9ejz-arlAg/maxresdefault.jpg

Solution

UAV mounted FSOC

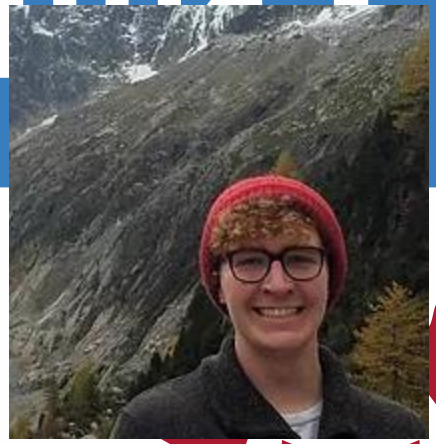
- Electro-optical transceiver
  - Small form-factor pluggable (SFP) module
- Near IR (850nm)
- DJ Scanning Galvanometer
- Static & Dynamic testing
- Raspberry Pi on-board



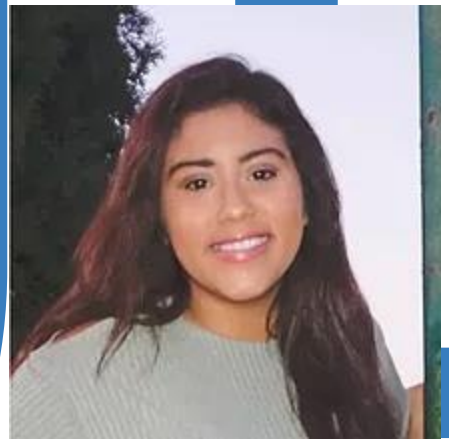
https://www.researchgate.net/publication/338257918/figure/fig1/AS:842165353721856@1577799275060/Flying-Ad-hoc-Network-FANET.ppm

The Team

- Ian: The CS Guy



- Natalia: The EE Girl



Timeline

Previous

- Design
- Ordering

Fall

- Static construction/testing

Spring

- Scanner
- Tracking

TASK	ASSIGNED TO	PROGRESS	START	END
Research and Development				
Static Design	Both	100%	9/12/21	9/15/21
Order parts	Ian	100%	9/15/21	10/1/21
Scanner Design	Both	0%	12/6/21	12/13/21
Tracking Algorithm	Both	0%	2/14/22	2/19/22
FANET Design	Both	0%	5/28/22	5/30/22
Static Design				
Construct Transmitter	Ian	0%	10/25/21	12/6/21
Construct Receiver	Natalia	0%	10/25/21	12/6/21
Lab Condition Testing	Both	0%	12/6/21	12/13/21
Single Motion Design				
Scanner Parts Ordering	Natalia	0%	12/13/21	12/18/21
Construct Scanner	Both	0%	1/10/22	1/17/22
Test Scanner	Natalia	0%	1/17/22	1/24/22
Scanner Tracking Implementation	Ian	0%	1/17/22	1/31/22
One way tracking testing	Both	0%	1/31/22	2/10/22
Dual Motion Design				
Mount receiver on drone	Natalia	0%	2/10/22	2/17/22
Test drone receiver while moving	Natalia	0%	2/17/22	3/10/22
Mount transmitter on drone	Ian	0%	2/10/22	2/17/22
Test drone transmitter while moving	Ian	0%	2/17/22	3/10/22
Test drone-to-drone communication	Both		3/10/22	4/14/22
Demonstrate FANET feasbility	Both	0%	4/14/22	4/21/22

Major Decisions

Decision matrices for most important decisions

- Scanning
  - Mirrors
- Computer Connection
  - Wire type
- Laser Generation
  - Wavelength
  - Speed

Cost

Estimated Cost

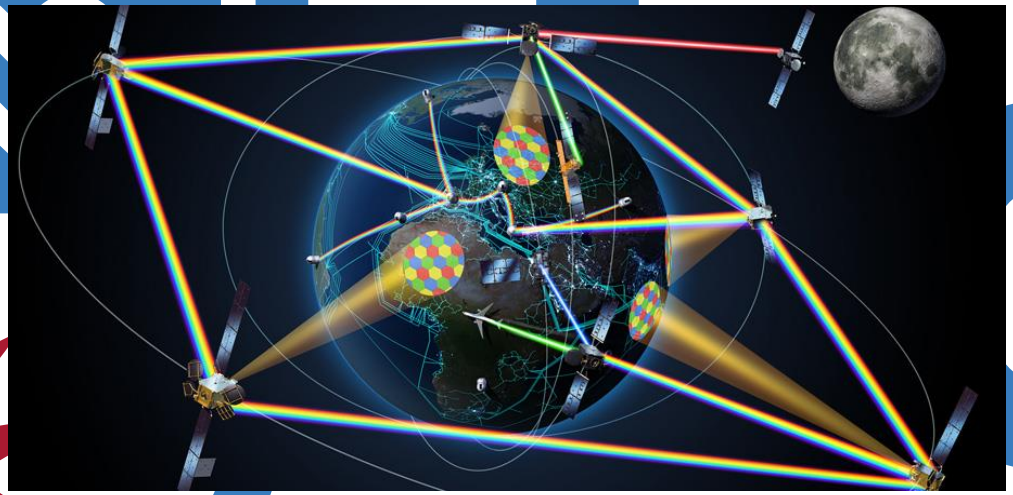
Supplies	Quantity	Cost ($) (total)	Need to Purchase
Raspberry Pi	2	$0.00	No
SFP	2	$26.01	Yes
Ethernet to USB-C Converter	2	$29.46	Yes
Ethernet Cable	2	$6.48	Yes
Lens	2	$17.54	Yes
Scanning Motors	2	$186.22	Yes
Media Converter	2	$42.54	Yes
Camera	2	$26.72	Yes
Laser (Aiming)	2	$39.00	Yes
Total		$397.97	Yes

Testing Results

Setup:	Bidirectional Throughput (Mbps)	Parallel Throughput (Mbps)	Unidirectional Throughput (Mbps)	Unidirectional Latency (ms)
Hardware-in-the-loop	941 ± 24	899 ± 71	941 ± 21	1.32 ± 0.32
Ethernet Control	924 ± 125	863 ± 112	940 ± 23	1.32 ± 0.30
Shared port	2893 ± 196	1632 ±260	2912 ± 195	1.05 ± 0.22
Host control	2719 ± 334	1577 ± 269	2714 ± 426	1.10 ± 0.26

Conclusion

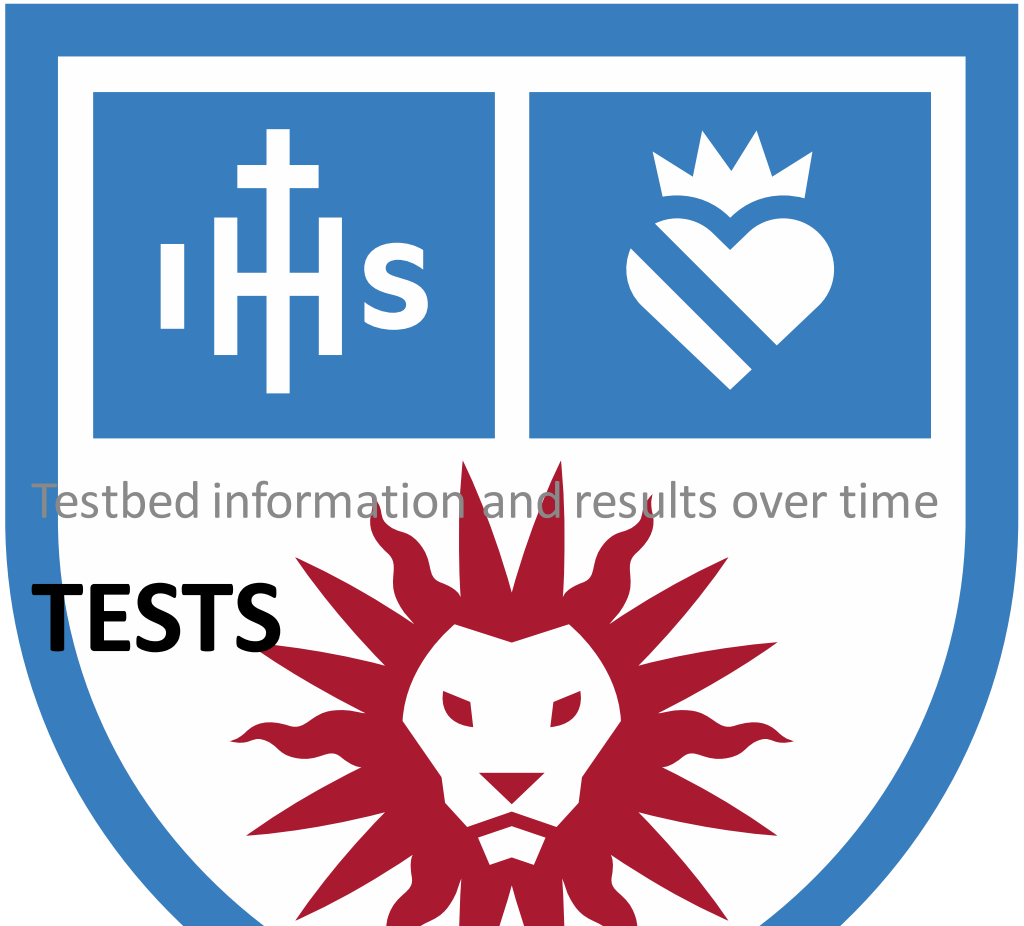
- Building a FSOC system using SFP modules
- Testing in a dynamic system
- Proof of concept for further implementation



https://spie.org/Images/Graphics/Newsroom/2020articles/B3_2_HYDRON_920.jpg

Questions?

Backup Slides



Testbed information and results over time

TESTS

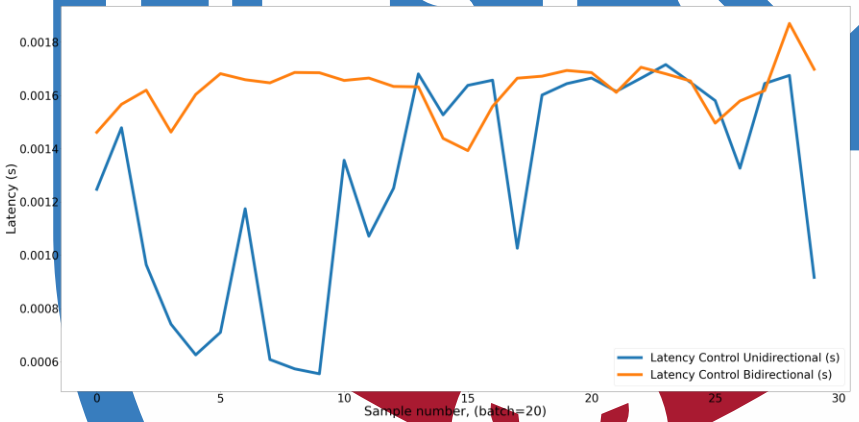
LO

Fiber Testbed

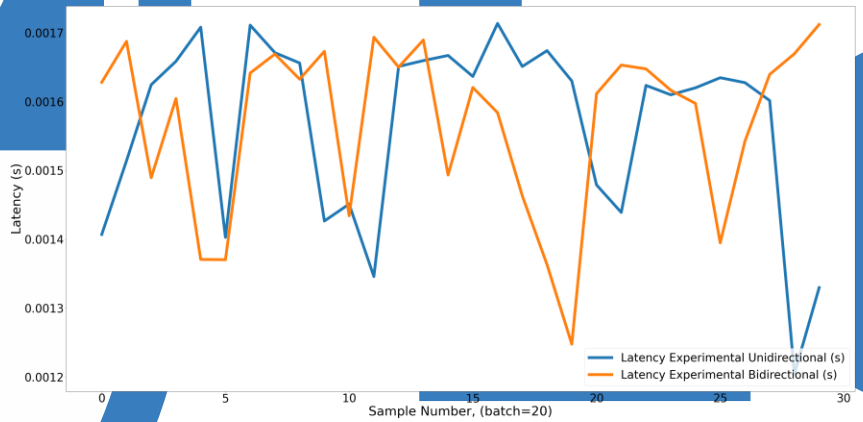
- Two VMs running 1 core, 2GB (3 core/4GB)
  - Lower performance due to system strain but reduced overhead for experimenters
  - Additional tests with more powerful machines required
- Bridged to Ethernet adapter
- Control was Ethernet cable only; experimental used SFP system

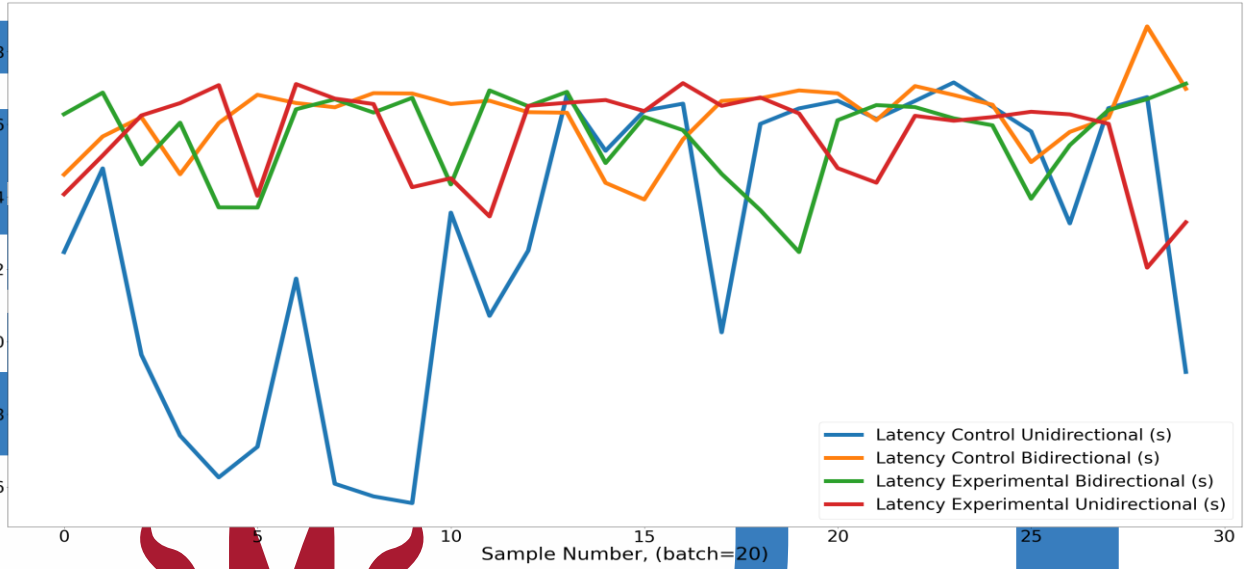
Latency Test

Control



Experimental





Latency Test (combined)

- Difference in speed at beginning likely a result of 'test-isms'

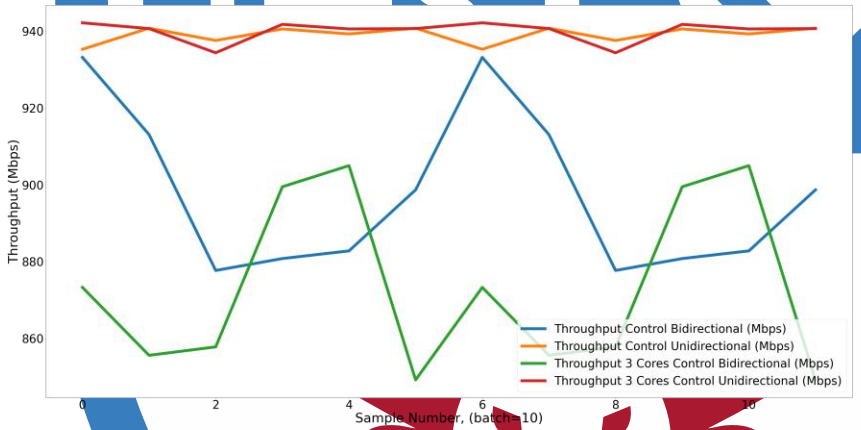
Latency Averages

Test	Average Latency (ms)
Average Latency Control Unidirectional	1.30
Average Latency Control Bidirectional	1.62
Average Latency Experimental Bidirectional	1.57
Average Latency Experimental Unidirectional	1.57

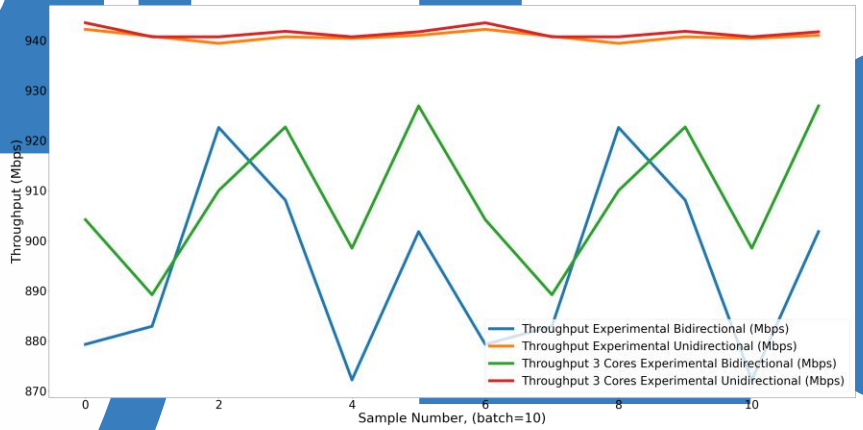
- Minor differences
- Much more data required to determine statistical significance

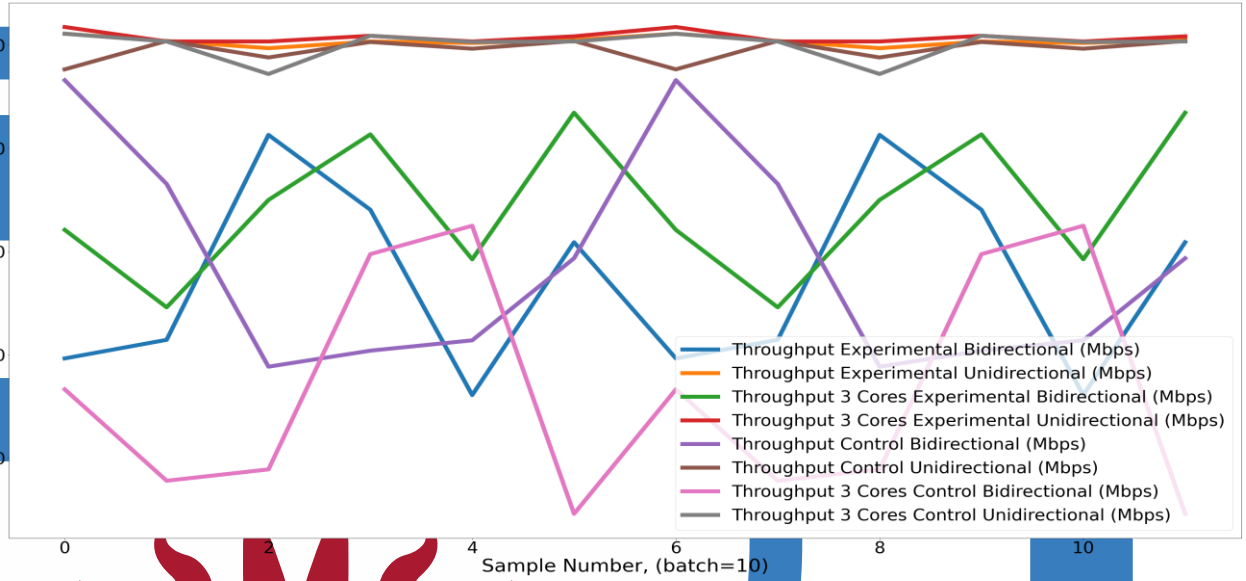
Throughput Tests

Control



Experimental





Throughput Test (combined)

- Experimental closely followed control, bidirectional slows down

Throughput Averages

- Bidirectional slower
- Unclear cause of slowdown
- Control/Experimental similar

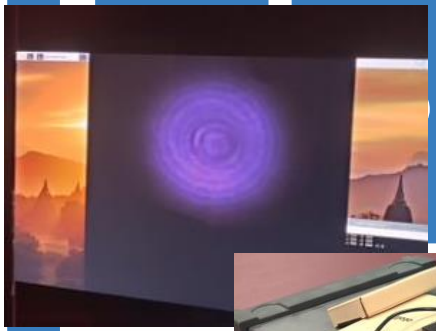
	Experimental Average Throughput (Mbps)	Control Average Throughput (Mbps)
Average Throughput Experimental Bidirectional	894	898
Average Throughput Experimental Unidirectional	941	939
Average Throughput 3 Cores Experimental Bidirectional	909	873
Average Throughput 3 Cores Experimental Unidirectional	942	940

What does the beam look like?

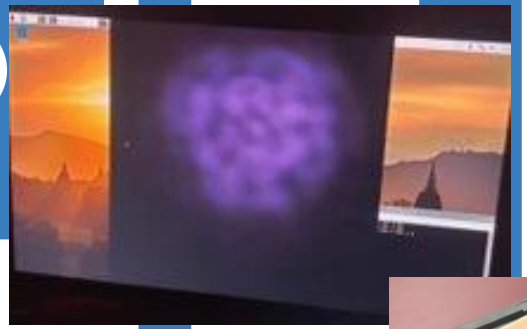
PATTERN ANALYSIS

Pattern Analysis – No Lens

SFP



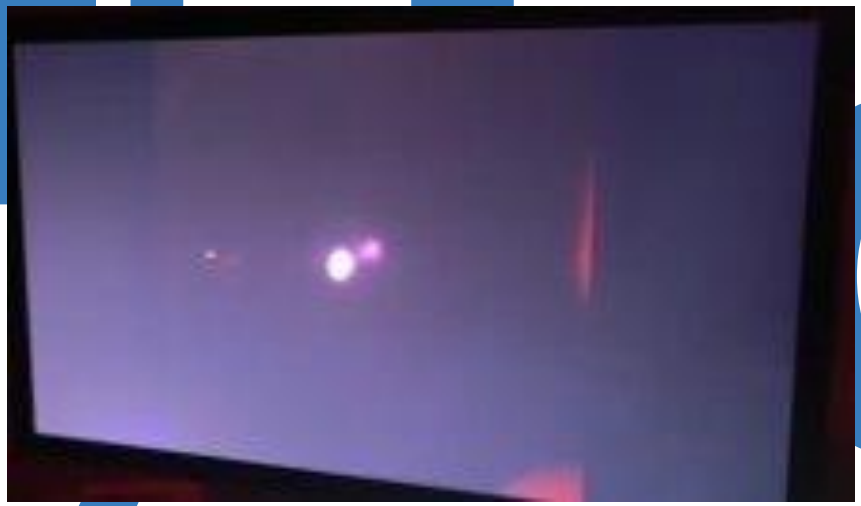
Fiber



Pattern Analysis - Lens

SFP with Lens

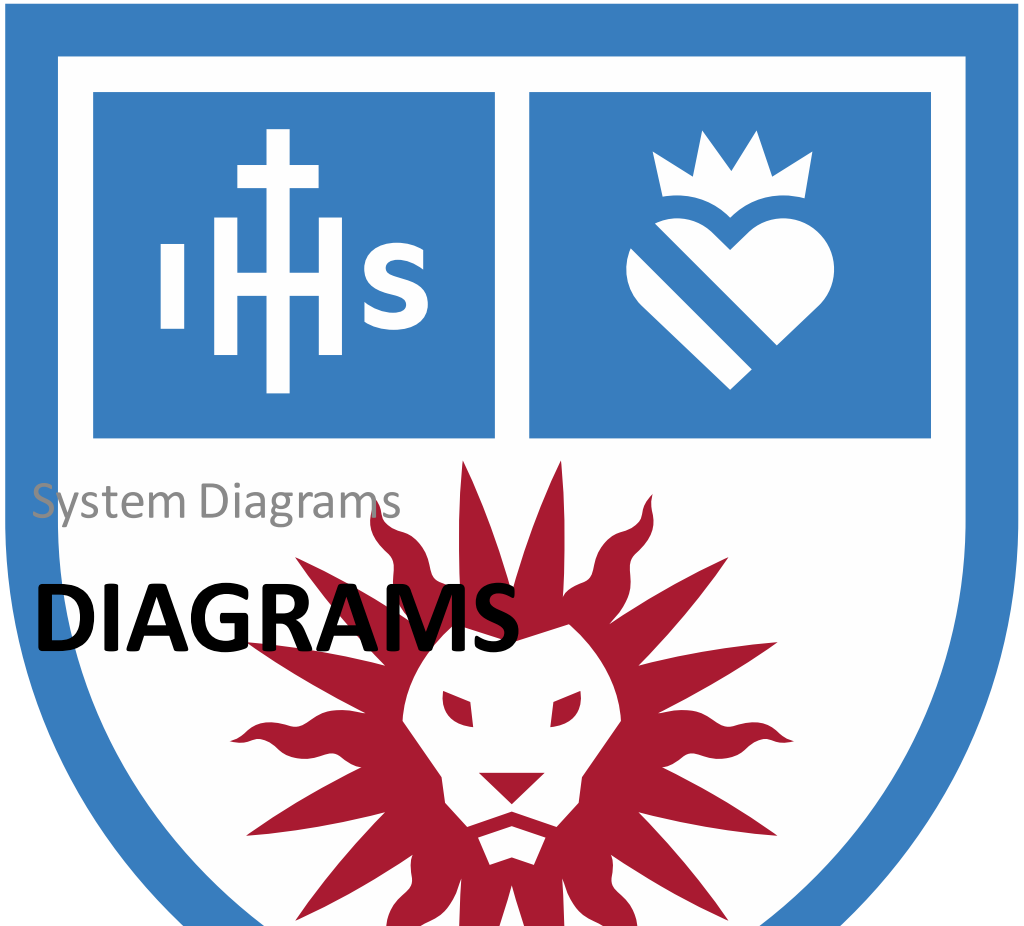
Fiber with Lens



Divergence

- Lens necessary
- Fiber has minimal impact
- Fiber changes scattering pattern

Setup	Divergence (mm)
SFP Only	117.7
Fiber Only	100.8
SFP with Lens	5.6
Fiber with Lens	4.8

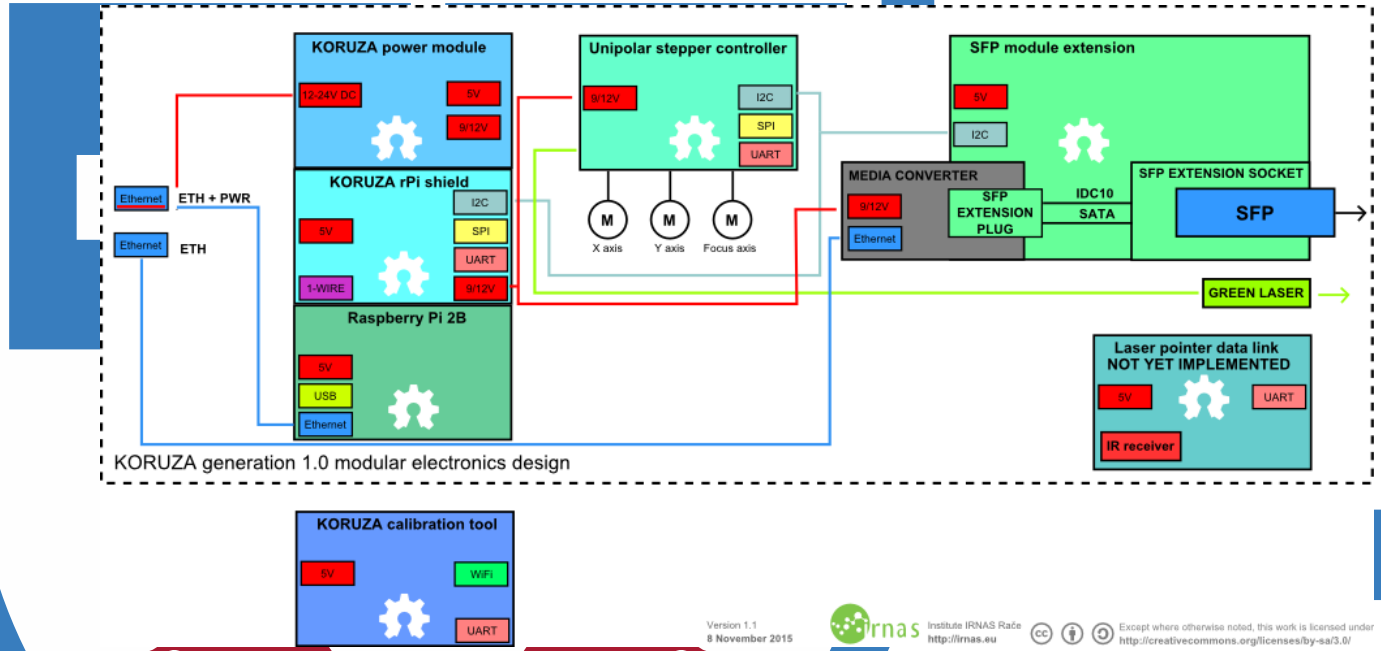


System Diagrams

DIAGRAMS

LO

KORUZA Diagram

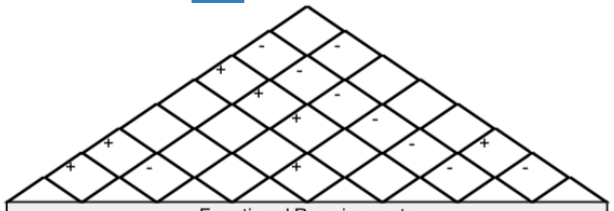


https://github.com/IRNAS/KORUZA/blob/master/diagrams/ElectronicsDiagram.png

KORUZA Links

- Description
  - https://www.hackster.io/musti/koruza-2b1824#toc-a--1-gbps-version-3
- Specifications
  - http://www.koruza.net/specs/
- GitHub
  - https://github.com/IRNAS/KORUZA

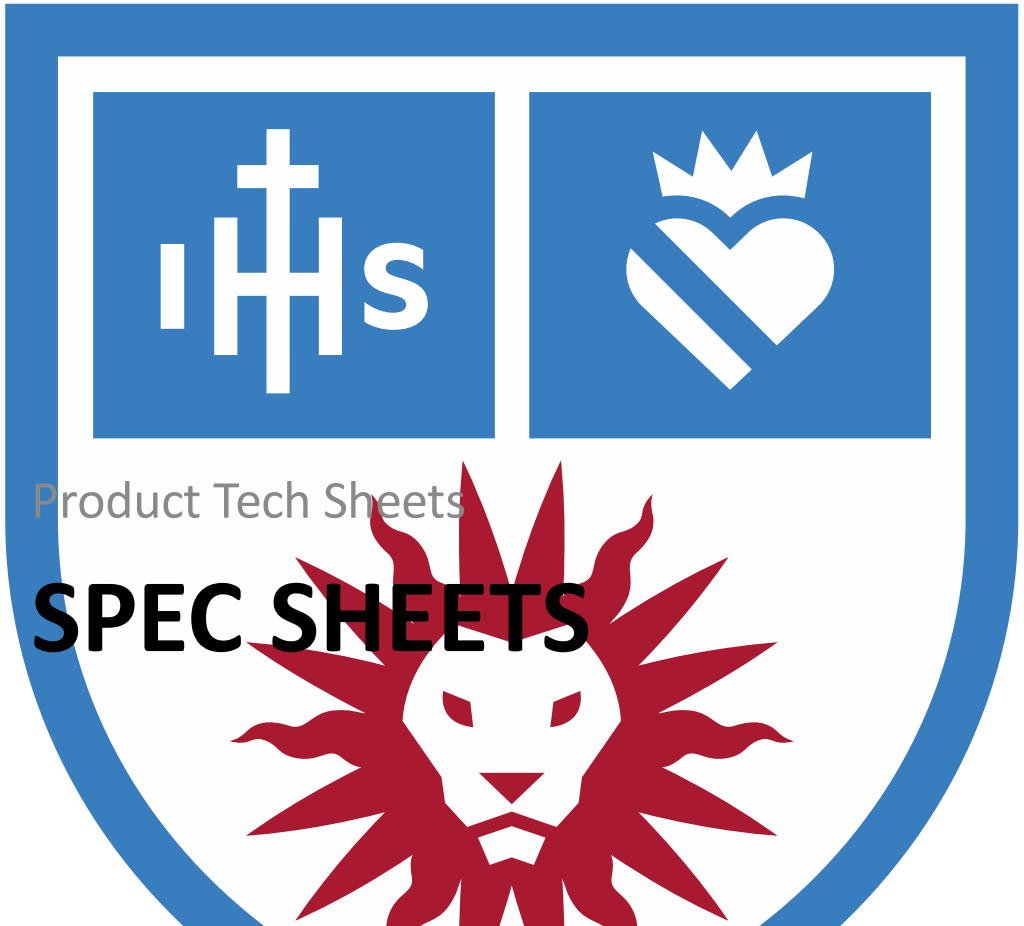
House of Quality



Relative Weight	Customer Importance	Direction of improvement	Customer Requirements	Driver Speed	Light Wavelength	Transceiver Speed	Tracking Distance and Speed	Tracking Update Speed	Bidirectional Simulateous Communication	Cost	UAV Network
			Direction of Improvement	+	-	+	+	+	+	-	+
18%	5	+	Bitrate	↑↑		↑↑		↑↑		↓↓	
32%	9	-	Sidelobe		↑						
7%	2	+	Over the horizon communication						↑		↑↑
29%	8	+	Weather resilient		↓						↑↑
11%	3	+	Continuous Communication						↑↑		↑↑
4%	1	+	Duplex Communication						↑↑	↓↓	
			Targets for Engineering Requirements	1 GHz	NIR	1 Gbps	100m/s at 100m ± 20mm	4.6 kHz	5Gpbps each way	$500	3 drones in a row

Functional Requirements

Technical Competitive Assessment

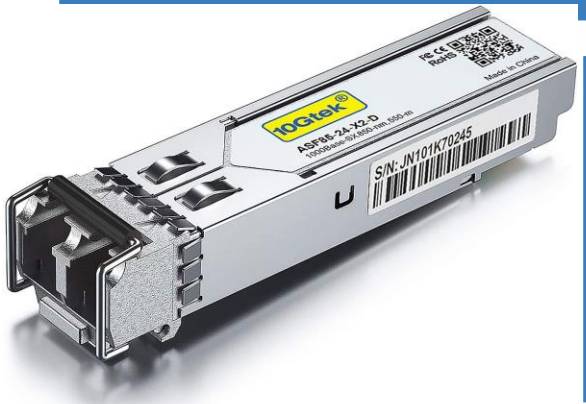


Product Tech Sheets

SPEC SHEETS

LO

SFP 1000Base-SX Specifications



https://www.amazon.com/10Gtek-GLC-SX-MMD-GLC-SX-MM-Transceiver-1000Base-SX/dp/B00U77VPX2/ref=sr_1_3?dchild=1&keywords=sfp%2B1000base-sx&qid=1633822790&sr=8-3&th=1

https://www.juniper.net/documentation/en_US/release-independent/junos/topics/reference/specifications/transceiver-m-mx-t-series-1000base-optical-specifications.pdf

Parameter	1000Base-SX
Rate	1000 Mbps
Optical Interface	Multimode
Maximum Distance	62.5/125 MMF Cable 656 ft/200 m
	50/125 MMF Cable 1640 ft/500 m
Transmitter Wavelength	770 through 860 nm
Average Launch Power	-9.5 through 0 dBm
Average Receive Power	-17 through 0 dBm
Receiver Saturation	0 dBm
Receiver Sensitivity	-17 dBm

Other Sheets

- https://github.com/LMU-Capstone/microp/blob/baf11cad1060482e7e44d2270b1c400f65a833ad/docs/product%20sheets/LC-Product-Spec.pdf