Lunar Wi-Fi Mapping and Design with Terrestrial Comparisons: Executive Summary

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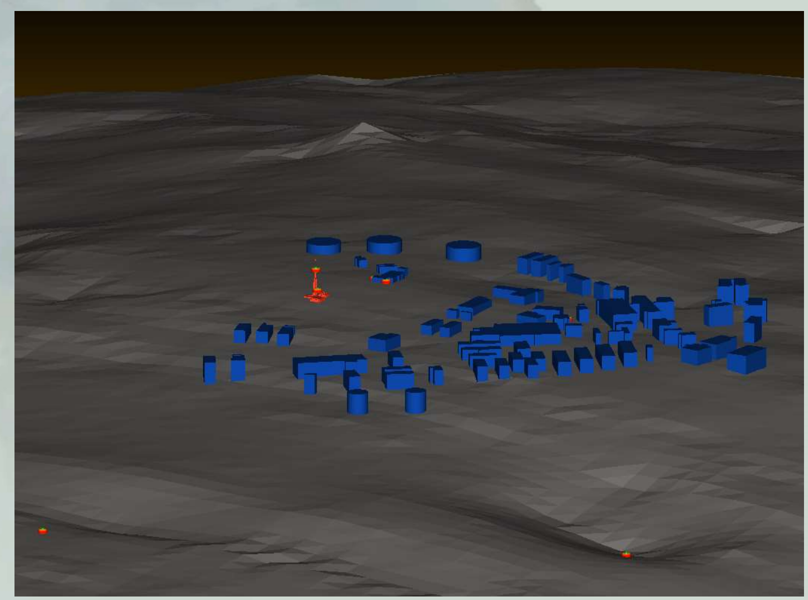


Steve Oleson (NASA GRC) and the Compass Team

Compass Study to Assess Wi-Fi Communications

- Space Act Agreement with two design objectives: Lunar and Terrestrial WiFi Networks
- The GRC Compass team is uniquely skilled in driving towards solution sets and it was determined that the Compass approach could be applied in designing a *representative* Wi-Fi network over both designated lunar and terrestrial areas.
- NASA's interest in the study:
  1. Compass to Contrast/Compare a representative Terrestrial 'outdoor/neighborhood' Wifi (Cleveland an example) with Lunar/Mars Wifi (Lunar South Pole an example)
  2. Compass team to gather lessons learned, new methodologies and innovative approaches in real time in order to ensure they can be applied to or enable future Compass designs.
  3. Provide Compass insight into additional best practices for distance collaboration / atypical designs that will be extensible to future Compass work as well as other NASA teams.

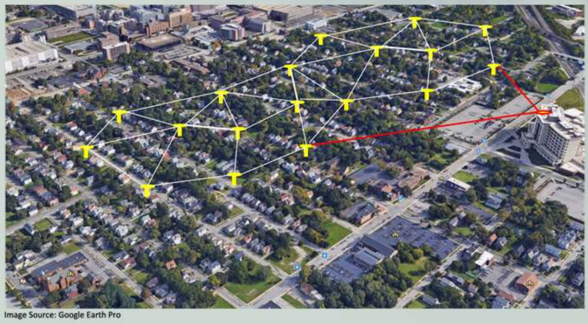
Approach

- Investigate Wi-Fi for a Terrestrial 'Neighborhood' and a 2030's Lunar Base
- What common approaches and technologies can be applied to both?
- How are they unique?
- Investigated a terrestrial network first – then applied to notional 2030's Lunar base

NASA Compass Team

- Lead – Steve Oleson
- Communications Engineers
  - Robert Jones
  - Dr. Ryan Toonen
  - Mike Cauley
- Systems Engineer – Betsy Turnbull
- Simulations: Mike Bur

Customer Representative – Jim Free



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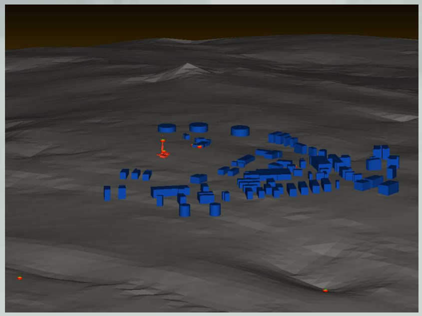
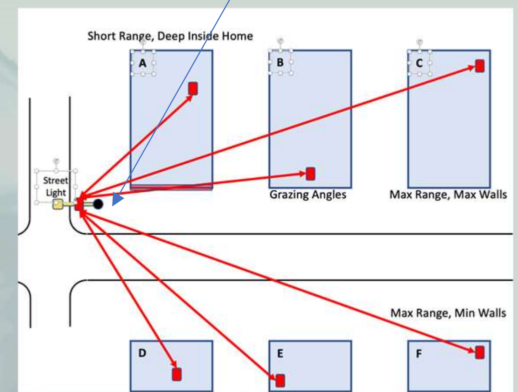


Terrestrial Wi-Fi: Executive Summary

- Developed models for service link: street light pole units to/from homes
  - Recommend Wi-Fi-6 to provide dual band (2.4GHz/5 GHz) to/from home using mesh networks (automatic network setups)
  - Should provide ~7.5 Mbps service for four people in each home (good enough for school, email, teleconference, video – NOT for 4K streaming or gaming)
  - FCC 4W transmitter limit may require repeaters in some households due to losses through walls
  - Estimated density of transceivers ~ every 100m on lightpoles
    - Spacing closer (50 m to 75 m) will allow 5 GHz (and more bandwidth!) to all households
  - Developed models and options for Backhaul: street light pole RF back to central Internet hub
    - Several options exist including 6 GHz RF, 60 GHz microwave, CBRS, Commercial



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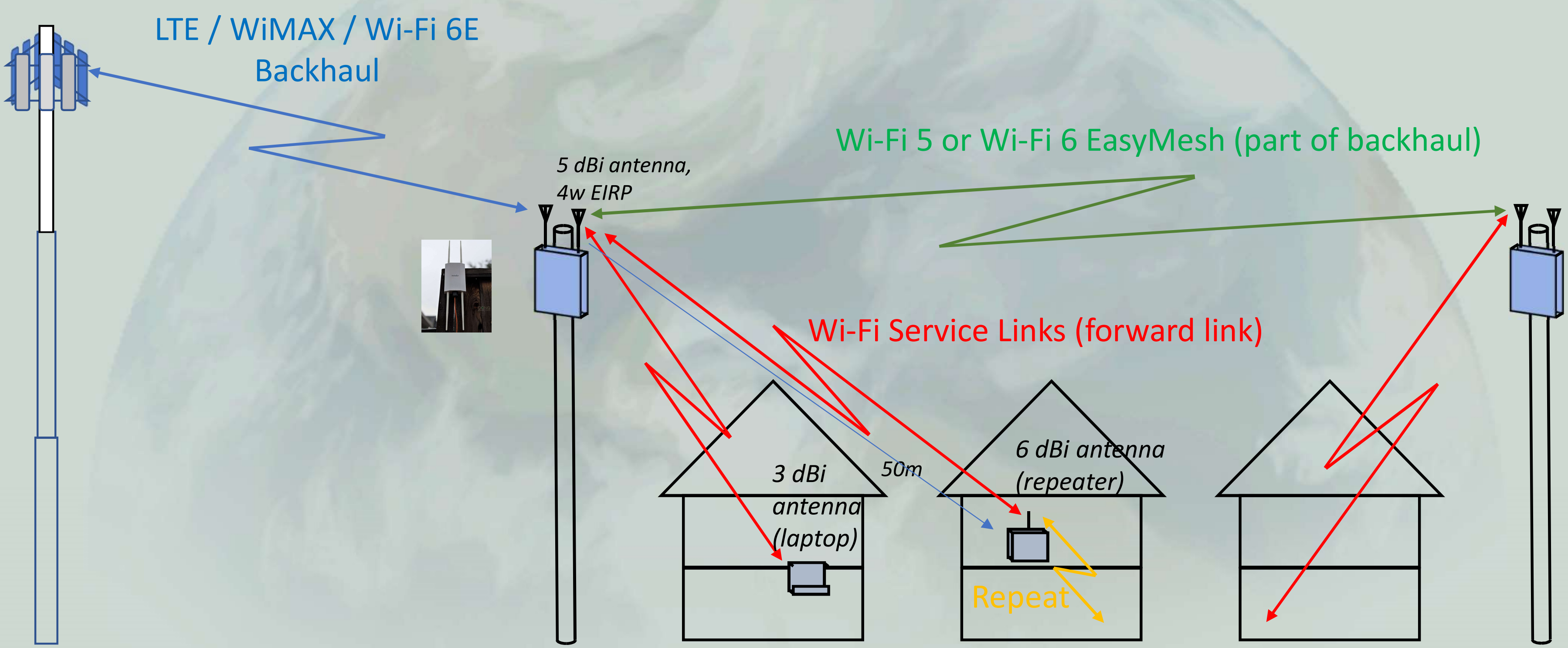
4 W EIRP (Effective isotropic radiated power) limit = transmit power and antenna gain

Example Link Performance of Notional Architecture



Terrestrial Design Summary

- Recommend 2.4/5 GHz frequencies to capture legacy user equipment (laptops, etc.)
- Recommend Wi-Fi 6 format, meshed networks, MIMO
- Rough link analyses show outdoor Transceivers installed ~ 100 m apart on lampposts (which provide power) can provide
  - Ample service for outdoor users
  - Sufficient service for indoor residential users
    - May require an indoor repeater to makeup for low performing user devices (laptops, tablets, smart phones)
    - OR
- Recommended RF (not wired) Backhaul which can be provided in various ways (non-technical considerations needed for downselect)
  - 6 GHz
  - CBRS
  - 60 GHz microwave
  - Commerical SAS
- For City of Cleveland Primary investment installation of ~ 20,000 lightpole access points (self networking), backhaul sites, Network oversight

Forward Link

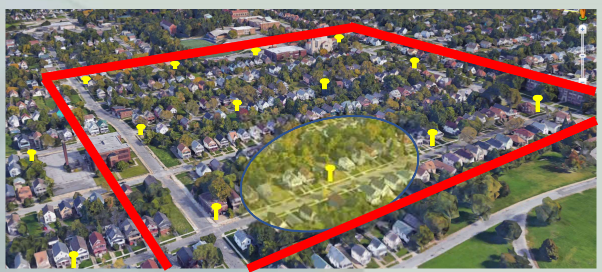


Image Source: Google Earth Pro

12 Access Points (AP) cover approximately 230 Residential Homes.
Approximately 19 Homes are 'served' per Access Point (The RF coverage must be greater)

Backhaul

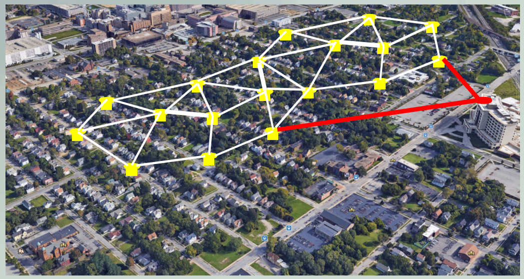


Image Source: Google Earth Pro

Things to look for when selecting Outdoor Access Points:

1. **Wi-Fi 6** – The new technologies built into Wi-Fi 6 (a 'friendly' name for 802.11ax) will make the user experience more reliable and fluid especially in highly congested frequency bands. (Wi-Fi 6 devices were first introduced in Early 2019.)
2. **Mesh Enabled** – Mesh networks are designed to efficiently 'hop' (or relay) traffic through a network of access points. Mesh devices automatically form a fabric of 'self organizing' and 'self healing' networks.
3. **'Managed'** – Device is designed to be part of a large remotely managed network (status, logs/events, configuration, remote reboot). Also allows network policies to be implemented.
4. **Dual Band (2.4 & 5 GHz)** – With concurrent connectivity. (6 GHz "Wi-Fi 6E" would be perfect for backhauls.)
5. **High Output Power** – As close to 1-Watt (+30 dBm) as possible and /or 4-Watts EIRP. This is the max allowed by the FCC.
6. **MIMO** – Multiple Input Multiple Output. Using multiple 'spatial streams' (Exploiting multiple RF paths between two devices). Many outdoor units are 2x2, but Wi-Fi 6 devices can go up to 8x8.
7. **Outdoor Rating** - IP67 rated devices are available and a good choice. Don't forget EDS protection
8. **PoE (Power-over Ethernet)** – Creates a single cable connection. Simplifies connection to other devices (Backhaul radios) (802.3at and/or 802.3af)
9. **Detachable Antennas** - Allows custom installation / coverage (e.g. sector antennas or remoting of antennas)

Representative Access Point (on Light pole)

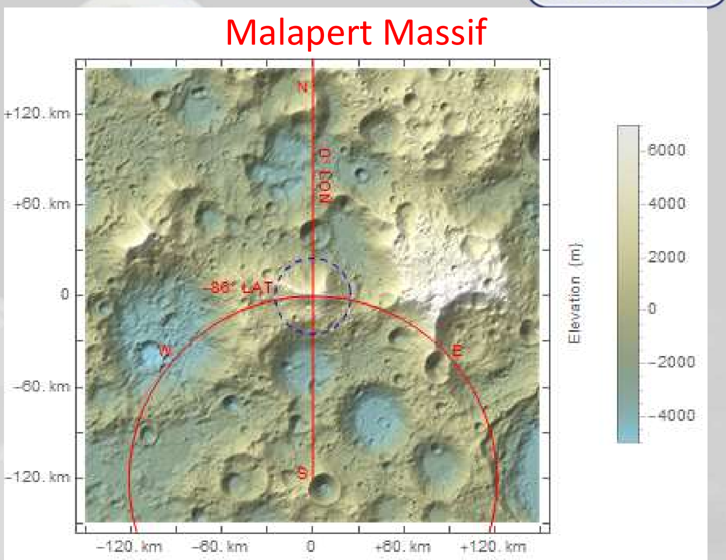
Wi-Fi Range Extender (in-home)

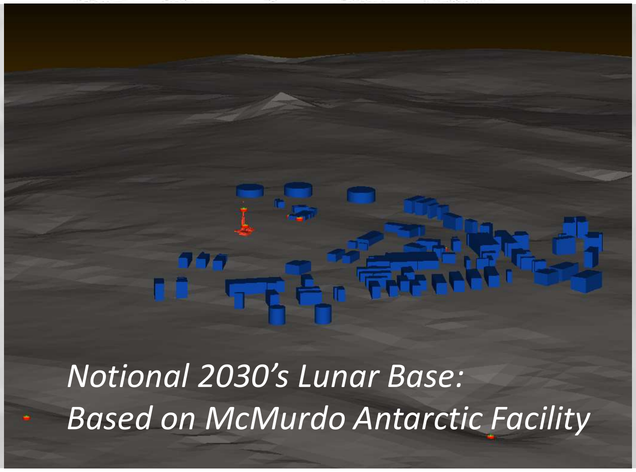
Backup Slides

Lunar Applications

Lunar Base Wi-Fi: Executive Summary

- Used same Frequencies as Terrestrial
- Permanent 2030s Moonbase on Malapert Massif:
  - Excellent annual Sun exposure
  - Excellent line-of-sight communication with DSN
  - Relatively close proximity to Shackleton crater (116 km)
- Performed multipath fade loss analysis to gauge link budget:
  - Quasi-Optical Shoot-and-Bounce Ray-Tracing Engine (ANSYS Savant)
  - Lunar Digital Elevation Map (from LRO LOLA mission)
  - 3-D Moonbase Model (McMurdo Station + Signal Tower)
- Assumed Lunar users are mobile or external to main habs/facilities (which are supplied by wire with power)
  - Recommend Wi-Fi-6 to provide dual band (2.4GHz/5 GHz) to/from mobile users using mesh networks (automatic network setups)
  - 8-m high transceivers mounted on wired infrastructure (habs, landers, etc) better than a central 32-m tower for local reception
  - Assuming FCC 4W ERIP limit 2.4 GHz could service non-line of sight users out to 400 m (5 GHz only to 100 m)
  - Assuming ~600 Mbps transceiver: Could provide live video link from 10-12 users
  - Adding more transceivers could add more bandwidth/users
- Results have provided direction to the newly formed *Lunar Architecture Team*




Notional 2030's Lunar Base: Based on McMurdo Antarctic Facility

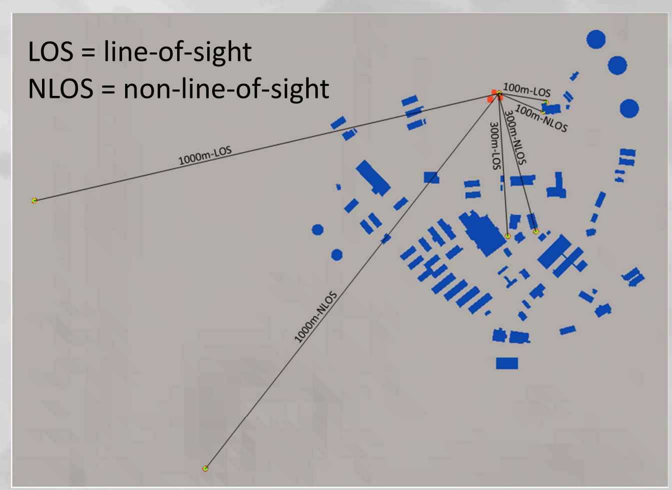
Overview

- **Compass Study Overview**
  - Models will be developed for a south pole lunar landing site, and for comparison the city of Cleveland in order to answer how terrestrial equipment and networks compare (and can be used on the moon/Mars) and how these extraterrestrial sites are unique.
  - Given specifications for signal strength, data rates, maximum elevation and other parameters, NASA GRC will perform
    - A Compass session to develop a potential configuration, and Wi-Fi coverage map with hardware locations
    - Applicable for a south pole lunar base as well as (for comparison and contrasting) the city of Cleveland, and perform a trade on the use of standard equipment to provide functionality.
    - Show the similarities and differences between terrestrial and moon/Mars Wi-Fi applications based on this work
  - The Compass team will consist of system engineers (LSM) and communication engineers (LC), and simulation and graphics.
  - Compass remote work and an atypical design (comm system only, terrestrial application) will assessed.

2030s 'Moon Base'

- McMurdo and Scott 3 km apart
- Rough Estimated Needs:
  - Speeds, # users (~200 people, 100 robotic platforms, density of users)
    - McMurdo 1200/5600 people /mi^2, CLE 5000 people / mi^2
  - Assume a McMurdo station and Scott Stations Malpert
  - Assume 'lamppost' style transmitters – 100-300 m apart?
    - No atmospheric losses, less building obstructions
    - Spectrum allocation
  - Will the Wi-Fi be able to tie back into Earth Internet? (albeit delayed)

Quasi-Optical *Shoot-and-Bounce* Ray Tracing for Simulating RF Scattering



Quasi-Optical *Shoot-and-Bounce* Ray Tracing for Simulating RF Scattering

Router Ht. {m}	2D Range {m}	LOS/NLOS	Rice Factor, K	Fade Loss† {dB}
8 (Rooftop)	100	LOS	4.495 ± 0.192	10.601
		NLOS	2.065 ± 0.115	16.042
	300	LOS	2.488 ± 0.096	14.889
		NLOS	1.265 ± 0.058	17.963
	1000	NLOS	13.63 ± 0.42	5.003
		NLOS	12.032 ± 0.82	5.372
32 (Tower)	100	LOS	51.31 ± 2.03	2.269
		NLOS	1.729 ± 0.095	16.866
	300	LOS	0 (Rayleigh)	20.141
		NLOS	0.465 ± 0.193	19.448
	1000	LOS	2.756 ± 0.16	14.279
		NLOS	1.243 ± 0.096	18.477

Notice: For a range of 100 m, the fade loss is comparable to the 8.93 dB computed for rooftop communication in a neighborhood (ITU-R P.1411-10).

†Fade Loss determined from a Rician/Rayleigh cumulative distribution function using 99% level of confidence.

Based on preliminary results the use of multiple rooftop routers – spaced 100 m apart - just as good as a single tall tower

Lunar Service Link Analysis Summation

- Preliminary Analyses trades distance between Service link transceivers (on wired facilities) to provide
- Signal strength using terrestrial bands with FCC limitations
  - 2.4 GHz: Sufficient signal (-70 dBm) to outdoor users up to 400 m away (non-line of sight: NLOS)
  - 5 GHz: Distance reduced to ~100m away (NLOS)
- Solutions to signal strength deficit
  - Explore using higher power allowable frequencies (like HLS 5.8 GHz)
- Assuming 50 Mbps for live video would limit service to 10-12 mobile users assuming the same terrestrial units limit of ~600 Mbps in total for all users within a 400 m distance
  - Placing transceivers ~200 m apart could allow more bandwidth and use of 5 GHz

Terrestrial Vs Lunar (2030 moonbase) Wi-Fi Summary

	Terrestrial	Lunar Base
FCC rules	RF Spectrum and power limitations, <4 W EIRP	For now, the terrestrial RF Spectrum and power limitations are baselined for the moon
Frequency	Service link: 2.4GHz/5 GHz Backhaul: RF 6 GHz	Service Link: 2.4 GHz/5 GHz Backhaul: wired (for fixed users), satellite thru Wi-Fi 'towers'
User Density	~19 households serviced by each transceiver (50 m from unit): ~ 75 users	~ 100 mobile users in 1 km diameter area
Wi-Fi Stations	Every 100m, existing street light poles (provides power)	On infrastructure elements, ~8m tall, powered by base power (wired)
Tie-in to WWW	RF Backhaul to main trunk	Limited Backhaul to earth through relay sats and or DTE: Lunar Internet to WWW (w appropriate firewalls)– up to 6 second delay?
Users	Outdoor and family dwellings (indoor)	Mobile and temporary users (fixed users with power should have data access using wired connections)
Equipment	COTS, rain/water proof (spec), temp limits, atmospheric cooling, terrestrial power, atmospheric losses	Different equipment: vacuum/space rated, radiation (boards different than terrestrial), dust, lunar environment wide temp extremes (impacts RF link noise at high temps). Possibly a Space Rated Software Defined Radio programmed to perform Wi-Fi