FREE SPACE OPTICS

TRANSPORTABLE TEST PLATFORM

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Abstract

The study examines potential approaches and benefits to government space agencies and industry regarding the development and testing of free space optics (FSO) satellite communication systems should government space agencies launch optical satellite payloads and/or develop a transportable test platform with which industry provided optical ground systems (OGSs) could interface.

The study examines atmospheric and environmental effects on FSO networks, as well as the multitude of mitigation techniques available to compensate for those effects. Research suggests that there are a multitude of potential techniques that could be implemented to mitigate the adverse effects of atmospheric/environmental conditions, and to optimize the effectiveness of FSO networks. Testing and selection of this broad array of techniques is a prerequisite to making FSO space segment systems and OGSs interoperable.

The study discusses testing that is required to define FSO standards. The establishment of interoperable standards is complicated by the existence of a multitude of potential schemes/specifications to address each mitigation/optimization challenge; very little is yet standardized. Standardization is further complicated by the fact that the selection of a design approach which benefits one consideration often disadvantages another consideration. Each mitigation techniques must be evaluated as an element of the complete system to gain an accurate understanding of its effects on system efficacy.

Transportable Test-platform

The study explores potential methods to test and evaluate the multitude of mitigation techniques and optimization strategies. The study recommends the development of a transportable test platform that can avail itself to a variety of atmospheric and environmental conditions as well as a variety of optical terminal designs.

The study examines methods to develop such a Transportable Optical Platform and communications Point of Presence (dubbed a TOP-POP) with which industry partners could integrate and test their optical ground systems (OGS) with government space agency provided optical space segment (be it optical communications or simply optical beacons).

The TOP-POP would be equipped with interfaces to industry built stationary OGSs. This primarily consists of communications interfaces and protocols including optical-to-optical, optical-to-RF and optical-to-copper. This will enable the evaluation and testing of advanced commercial communication relay capabilities including:

- Interoperability testing between providers and users
- High data rate routing and processing
- Transition paths to operations

Communications POP

The TOP-POP would function as a communications point of presence (POP) providing onboard data processing, data storage, and data routing through the satellite(s) and/or a flat-sat. To insure interoperability with terrestrial systems, standard optical telecommunications protocols and standards would be implemented.

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Abstract: This paper examines potential approaches and benefits to NASA and United States (US) industry regarding the development and testing of free space optics (FSO) satellite communication systems should NASA launch optical satellite payloads and/or develop a transportable test platform with which industry provided optical ground systems (OGSs) could interface. Research suggests that there are a multitude of potential specifications which would need to be finalized as a prerequisite to making FSO space segment systems and OGSs interoperable. These issues as explored in this paper include:

- **Acquisition processes**
- **Coarse and fine tracking**
- **Synchronization**
- **Wavelengths**
- **Modulation schemes**
- **Aperture size(s)/averaging**
- **Spatial diversity**
- **Site diversity (alternate FSO links or hybrid RF/Optical networks)**
- **Coding/FEC**
- **Radio channel for command and control**
- **Jitter isolation and rejection**
- **Transport layer methods**
- **Re-transmission protocols**
- **Reconfiguration and rerouting**
- **Quality of Service (QoS) control**
- **Security**

The establishment of interoperable standards is complicated by the existence of a multitude of potential schemes/specifications to address each of the above issues; very little is yet standardized. Standardization is further complicated by the fact that the selection of a design approach which benefits one consideration often disadvantages another consideration. Each of these topics must be evaluated juxtaposed the others to gain a complete understanding of their efficacy.

This paper also examines atmospheric and environmental effects on FSO networks, as well as the multitude of mitigation techniques available to compensate for those effects. The paper further explores potential methods to evaluate those mitigation techniques by utilizing a transportable test platform that can avail itself to a variety of atmospheric and

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environmental conditions.

This paper also examines methods to develop a transportable test platform with which industry partners could integrate their OGS systems with a NASA provided optical space segment (be it optical communications or simply optical beacons). The result being a transportable test platform upon which a multitude of potential industry solutions could be developed, tested and evaluated.

I. FSO CHALLENGES

In addition to determining the correct design parameters to meet the specifications necessary to achieve the desired communications performance and be interoperable with any prior existing components such as an optical space terminal (OST), the OGS must be designed to mitigate the adverse effects of clouds, atmospheric turbulence and other environmental conditions. When light is transmitted through the air as in optical wireless systems like FSO, it must contend with the atmosphere. The fundamental limitation of FSO communications arises from the environment through which it propagates. Although relatively unaffected by rain and snow, FSO communication systems can be severely affected by clouds, fog, atmospheric turbulence and other environmental influences.

Atmospheric Turbulence

Atmospheric turbulence is primarily created from conditions existing in the Earth's atmosphere, up to 30 km from the Earth's surface. As the atmosphere causes divergence of the uplink beam for the first 30 km of its path, any divergence is compounded as the beam travels the rest of the distance to its target satellite. For downlink transmissions, the beam is unaffected until the last 30 km of its path; therefore, the divergence of the beam is less significant for downlink propagation. Mitigation techniques are therefore especially critical for uplinks.

Clouds/Fog

Clouds and fog are vapor composed of water droplets, which are only a few hundred microns in diameter but can modify light characteristics or completely hinder the passage of light through a combination of absorption, scattering, and reflection. This can lead to a decrease in the power density of the transmitted beam, decreasing the effective distance of an FSO link.

Scintillation

Scintillation is the spatial variation in light intensity caused by atmospheric attenuation and turbulence. Such turbulence is caused by wind and temperature gradients that create pockets of air with rapidly varying densities and, therefore, fast-changing indices of optical reflection. These air pockets act like lenses that focus and de-focus the beam; leading to signal fades and increases in the bit-error rates of FSO systems, particularly in the presence of direct sunlight. Scintillation is the major cause of degradation in the performance of FSO systems.

Beam Wander and Beam Spreading

Beam wander arises when a turbulent wind current larger than the diameter of the transmitted optical beam causes a displacement of the transmitted beam. Beam wander may also be the result of seismic activity that causes a relative displacement between the position of the transmitting laser and the receiver aperture. Beam spreading takes place when the beam is diffracted and scattered independently leading to distortion of the received wavefront.

Beam Divergence Loss

A beam divergence results from diffraction near the receiver aperture as the optical beam propagates through the atmosphere. A portion of the transmitted beam is not collected by the receiver resulting in loss. This loss increases with the link length unless the receiver aperture is increased, or receiver diversity is in place. The design parameters of the FSO link must balance the need for a broad beam to ensure that the beam reaches the satellite with the need to narrow the beam sufficiently to ensure transmit power requirements are met.

Atmospheric Seeing

Atmospheric seeing refers to the perturbations of the optical beam associated with the coherence length of the atmosphere. This leads to the blurring of the received signal. However, the effects of atmospheric seeing can be limited by adaptive optics or array detectors.

Angle-of-Arrival Fluctuations

Turbulence in the atmosphere will distort the laser beam wavefront arriving at the receiver which leads to spot motion or image dancing at the focal plane of the receiver. However, the effects of angle-of-arrival fluctuations can be compensated using adaptive optics or fast beam steering mirrors.

Solar Interference

As FSO terminals use highly sensitive receivers used in combination with large-aperture lenses, natural background light can interfere with signal reception. This is especially the case with the background noise from the sun. Narrow band optical filters can in part control the noise.

Pointing Stability: Vibration and Sway

Movement such as vibrations, jarring or sway adversely affect the accurate transmission of the optical beam and/or the alignment of the optical receiver. As stationary OGSs are built into permanent structures, they are designed to be capable of handling the majority of movement resulting from vibration and sway generated from environmental conditions. Transportable Optical Ground Stations (TOGSs) may be deployed on auto or manually leveling supports that compensate for ground roughness. Casings protect the optics and hardware during transport. TOGS are commonly mounted on anti-shock/vibration elements to protect the equipment during transport and also dampen vibration and sway during operation.

Summary

There are multiple external parameters related to the environment in which optical terminals must operate that affect the operation and performance of FSO systems including visibility, atmospheric attenuation, scintillation, deployment distance, window loss, and pointing loss. Many of these parameters are not independent but rather cross affect each other in determining overall system performance. Therefore, in order to truly evaluate both the ground and space elements of the system architecture, and/or the performance of the system itself, testing of those systems must be conducted under a variety of environmental conditions and from a variety of physical locations; just as it will be in real-life applications. To conduct such testing, a transportable platform must be used.

II. MITIGATION STATEGIES TO BE DEVELOPED AND TESTED

As discussed above, environmental conditions create significant obstructions to completing Satellite to Ground Links (SGL) with OGSs. Multiple potential approaches exist to negate environmental effects and maximize transmission efficiency. Those approaches may be considered in two basic categories: 1) methods to improve the reliably of the FSO link and 2) methods to bypass a faulty link in favor of a reliable alternate link.

Mitigation Methods Under Evaluation to Improve the Reliability of the FSO Link

Aperture Averaging

Aperture averaging is a technique used to mitigate the effect of atmospheric turbulence by increasing the size of the receiver aperture averaging out fluctuations caused by small eddies. Studies suggest that aperture averaging may be advantageous only for satellite downlink (not uplink). However, an increase in the receiver aperture size will also increase the amount of background noise collected by the receiver; adding to the complexity of balancing design decisions.

Adaptive Optics (AO)

Adaptive Optics are systems built into the OGS that pre-correct the beam in real time by converting the wavefront measurement into actuator commands to minimize the wavefront error before transmitting it into the atmosphere. This approach in part mitigates the effect of atmospheric turbulence.

Re-transmission

Re-transmission protocols such as automatic repeat request (ARR) may be employed wherein if the receiver does not acknowledge receipt of a transmitted packet within a specified time frame, the packet is re-transmitted. Variants include selective repeat ARQ (SR-ARQ), hybrid-ARQ (H-ARQ), cooperative diversity with ARQ (C-ARQ), modified cooperative diversity with ARQ (MC-ARQ) and Rateless Round Robin.

QoS

In order to optimize performance, Quality of Service control protocols must be decided upon and implemented to measure data rate, latency, delay jitter, data loss, energy consumption, reliability and throughput efficiency from one node to another within an FSO network. QoS classes under consideration by NASA include:

- *Latency-intolerant, High availability* wherein high priority data is transferred from the user platform to the ground via relay satellite as RF data transfer links become available.
- *Latency-intolerant, Lower availability* wherein routine priority data is transferred from the user platform to the ground via relay satellite as optical data transfer links become available.

- *Latency-tolerant, guaranteed delivery* wherein routine data is transferred subject to availability from the user platform to the ground via relay satellite. Store and forward capabilities are utilized.

Spatial Diversity

An OGS can utilize an array of smaller receiver apertures instead of a single large aperture (monolithic-aperture) so that multiple copies of the signal that are mutually uncorrelated can be received. In the multi-aperture approach, the antenna separation at the transmitter or receiver needs to be at least the coherence length of the atmosphere to make the beams uncorrelated. This separation is sufficient to eliminate many of the adverse effects of environmental conditions. Within this approach, there are multiple potential configurations.

SIMO: Single aperture for input (receive) and multiple apertures for output (transmit).

MIMO: Multiple apertures for input (receive) and multiple apertures for output (transmit).

With multi-aperture approaches, it is necessary to combine the signals from the aperture array. This can be done by optically combining the multiple beams before photodetection. Alternatively, the digitized signals may be combined after photodetection by digitally combining them.

Methods to Bypass a Faulty Link in Favor of a Reliable Alternate Link

Site Diversity (Geographic Diversity)

A solution widely adopted to minimize adverse environmental (weather) effects is site diversity which involves deploying OGSs in geographic locations carefully selected to minimize the probability of disturbances by adverse weather. For example, a single OGS site may be available anywhere from 30% of the time in Central Europe to 80% of the time in beneficial weather locations. The site diversity approach is adopted by BridgeSat, Laser Light, Hughes and Analytical Space; and is likely to be adopted by any organization deploying an OSN.

While having multiple potential OGSs in varied locations improves the likelihood of establishing a successful link, tremendous advantages can also be made by choosing the precise location of each OGS to minimize the likelihood of the link being adversely affected by weather. Weather patterns can be analyzed to determine, in aggregate, which combination of geographic ground sites will enable the transmission of the largest amount of data, to the greatest potential population, with the most reliability. For example, considerations are given to sites with relatively close proximity, but which are unlikely to be obscured by poor weather at the same time; essentially where adverse weather is likely to clear one site before that weather condition affects another site.

Cognitive Diversity Network

As a multitude of sites may be available through which to route traffic, a dynamic and real-time decision-making algorithm must be used to determine how the traffic is routed. Such approaches are similar to NASA's Delay/Disruption Tolerant Network (DTN) computer networking model. The network must take into account the geographic source of the data, the priority of the data (streaming/real-time or "store and forward"), the target geographic target end destination of the data, the available data paths (satellite, terrestrial fiber networks, last mile delivery paths), the relative data speeds of the available data paths, and the weather. Laser Light's proposed site diversity network utilizes artificial intelligence and machine learning algorithms to sense, predict and infer network conditions to dynamically mange transmission of information between communication nodes. Hughes is designing a similar network using a centralized software-defined networking (SDN) based decision making for optimizing traffic route determination. BridgeSat has proposed a network called Star Beam which they represent will, in real time, makes calculations to automatically route data using the most efficient data path considering real-time weather conditions. Other users/operators attempting to efficiently transport data via FSO platforms will likely develop similar methodologies.

RF/FSO Default Links (Hybrid Architecture)

While RF systems are typically susceptible to rain, FSO systems are typically susceptible to fog and clouds. However, when optical SGL transmissions fail due to environmental conditions, traditional RF terminals operating in common bands such as X, Ku and Ka can often close the link. One approach to mitigate the failure of an FSO link is the inclusion of an RF link to operate as a failover from the FSO link. The disadvantages of this approach are the cost of the redundant links and the significantly reduced data rate of the RF link. Several topology control methods have been considered for FSO network applications. To enable the RF and FSO systems to efficiently work in tandem and save channel bandwidth, an adaptive joint coding scheme wherein both systems are active might be implemented.

Other Areas Where Further Industry Development and Testing are Required

Although OGS terminals build on the design framework of FSO networks, there are a significant number of parameters which must be addressed when designing an OGS system, and for each of those parameters there are a multitude of potential schemes that may be employed. Often these schemes are mutually exclusive meaning they are not compatible with alternate approaches. This is further complicated as increased performance or benefit from one change often has adverse consequences on another factor. As a result, there are vast numbers of potential designs which when deployed would not be interoperable. Below are examples of some of the parameters which must be addressed when designing an OGS and OCP so that the two can efficiently establish and maintain a communications link, as well as examples of the numerous potential variations within each design parameter.

PAT (Pointing, Acquisition, and Tracking)

Because of the large distance between OGSs and FSO satellites and the narrow diameter of the beam that connects them, accurate and reliable pointing is a non-trivial task. Synchronization of the two end transceivers compounds this challenge, especially if the OGS is transportable. OGS developers are currently evaluating multiple different PAT methods.

Pointing System (Coarse Pointing and Fine Pointing)

The first step in the synchronization process is the coarse-pointing, often via a gimbal. Coarse-pointing systems use a beacon signal with a wide divergence angle/field of view (FOV) but a lower date rate to make an original handshake. Once the beacon signal is detected, the receiving terminal uses beam steering elements (often fast steering mirrors) to point a beam with a narrower divergence angle (but greater data rates) towards the initiating terminal, forming a LOS link. The controller logic on the satellite gradually narrows its FOV until both systems have locked onto each other's signal. Alternatively, a coarse-sensing system implementing a wide FOV at the receiver can be implemented and the beam can then be narrowed to create the LOS link, or an omnidirectional beacon mounted on gimbals can be used to exchange location information.

Acquisition

It is possible that multiple optical beams in addition to the desired beam can be intercepted by a receiver aperture, whether the receiver aperture is on a spacecraft or on the ground. The receiver must determine which optical beam should be decoded. A methodology is necessary to accurately make this determination. Multiple potential models exist (i.e. binary morphological technique). Additionally, a methodology is required to synchronize the optical transceivers so that they point to each other simultaneously. As with tracking, this process of acquisition and synchronization is further complicated if one or both of the optical transceiver platforms are in motion.

Tracking

Due to the narrow beam width of the optical transmission, tracking provides the same challenges as pointing with the additional challenge of compensating for the movement of the optical payload. FSO links between non-stationary transceivers need very high pointing accuracy and very high resiliency of the alignment of the optical beams as any misalignment may result in reduced data capacity and outages.

Modulation

Multiple modulation schemes may be utilized to achieve improved power and bandwidth efficiency. These potential approaches either must be selected prior to the launch of a system, or the system must remain flexible enough to switch among the various potential schemes. While On-off Keying (OOK), Differential Phase Shift Keying (DPSK), and Pulse Position Modulation (PPM) seem to have wide acceptance, multiple other potential modulation schemes are being considered.

Adaptive Modulation

Adaptive Modulation may also be used to improve power and bandwidth efficiency. Examples include adaptive coding, variable rate, variable power adaptation, channel inversion, truncated channel inversion, optical sub-carrier intensity modulation, multiple sub-carrier intensity modulation, and differential phase shift keying.

Coding

As with other data transmissions, error control coding methods can be utilized in FSO architectures to minimize data loss. These include different Forward Error Correction (FEC) schemes such as Reed-Solomon (RS) codes, Turbo codes, convolutional codes, trellis-coded modulation (TCM), and low-density parity-check (LDPC).

Wavelength

Choice of wavelength affects both the link performance and the detector sensitivity. As tradeoffs exist between the antenna gain (better at lower wavelengths) and the link quality (better at higher wavelengths), the design of the FSO link must be optimized with these considerations in mind to achieve optimal performance. Optical C-Band (1530-1565 nm) is a desirable and commonly adopted wavelength in the US.

Coherent versus Non-Coherent Beams

The space segment optical beam and the ground segment optical beam must both utilize either non-coherent or coherent beams (meaning their phase, frequency and waveform are coordinated). Their relative polarities must also be coordinated.

Radio Channel for Command and Data Handling (C&DH)

Radio channel for command and control and data handling (C&DH) of FSO space platform requires dynamic autonomous reconfiguration both in the hardware and software needed to maximize the availability and capacity for operational scenarios. Issues such as dynamic rate allocation and routing and topology monitoring remain to be developed and tested. Techniques and hardware required to effectively integrate FSO and RF system operations remains to be explored.

FSO Networking

While development of FSO hardware has momentum, relatively little field-testing of FSO networks has been conducted. Multiple areas of evaluation remain to be explored including dynamic and adaptive routing; cooperative diversity techniques, the testing of data speeds, packet loss, bit error rate (BER), jitter, latency, delay, and fairness (QoS). This testing must be done in a dynamic environment allowing for changes of the multiple potential mitigation techniques, operational protocols and atmospheric environments.

Required Additional Research, Testing and Standardization

Despite the many developments, research on full and efficient utilization of FSO technology is still in its infancy. Significant research is still required to determine capabilities, identify potential issues, test performance and interoperability, and resolve issues. Once those issues are resolved, standardization will be necessary to ensure interoperability among industry and government produced components.

III. FSO PAYLOADS

It is anticipated that NASA may consider a variety of capabilities when selecting optical payloads to launch. Until industry standards are established, each OGS manufacture likely has or will develop their own optical and communication protocols based on their individual design decisions and perceived mission objectives. For their OGS to close the link with a NASA provisioned optical payload, specific protocols/standards concerning PAT, synchronization, modulation, coding, FEC, transport layer, wavelength, aperture size, AO, synchronization, C&DH, QoS, and atmospheric/environmental mitigation must be in place on the satellite. One option may be to launch optical payloads with set protocols; however, this would necessitate testing being limited to OGSs with characteristics consistent with those parameters. Another option might be to launch payloads with programable components (i.e. modulator/demodulator) that can be altered to meet a multitude of specifications, enabling testing of a variety of OGSs. Such a software defined optical payload would enable the testing of a greater number of design and protocol variables.

However, as the space segment and ground segment must be highly coordinated to complete the communications link (modulation frequencies, synchronization, etc.) it is possible that an individual space segment optical platform will not interface with each industry partner's OGS. However even in such circumstances, minimum testing of PAT functions can still be achieved by the provision of an optical beacon on the payload. The concept is to install an optical beacon on a satellite which OGSs can acquire and lock on in order to perform PAT testing. These beacons would be for PAT only; they would not include communications transmissions. While only PAT and not communications transmissions could be tested, a variety of controlled conditions could be evaluated.

The communications testing component might be accomplished on the ground using a mast mounted NASA OCP or a flat-sat; or at least the optical module portion of the payload. While a trailer mounted OCP/flat-sat would yield limited useful testing data on the optical link itself regarding atmospheric issues, the communications protocols could be tested thoroughly. A multitude of communications protocols necessary for closing the link with individual OGS partners could be integrated (swapped) on the NASA OCP/flat-sat test platform to accommodate their unique specifications.

IV. PROPOSED TRANSPORTABLE TEST PLATFORM

There are multiple limiting factors to the rapid development of FSO technology by US industry. One key issue is the lack of resources to test system components. A transportable test platform capable of being transported to, and integrating with, commercially developed stationary ground terminals is needed. In addition to providing US industry partners with the tools they need to accelerate their development, ensuring that US industry stays at the forefront of FSO technology applications, the project would provide NASA a baseline (common) test platform with which NASA can evaluate industry partners' progress and capabilities.

The test platform must provide the ability to conduct experiments to test atmospheric effects on FSO operations and transmissions and to test the mitigation of those effects through the implementation of techniques such as spatial diversity, site diversity, data rerouting and hybrid optical/RF networks. This trailer-based test bed would consist of a Transportable Optical Platform and communications Point of Presence (TOP-POP). It would incorporate a multitude of elements/capabilities as further set forth below.

1. The TOP-POP would be equipped with interfaces to industry built stationary OGSs. This primarily consists of communications interfaces and protocols including optical-to-optical, optical-to-RF and optical-to-copper. This will enable the evaluation and testing of advanced US commercial communication relay capabilities.

2. A communication point of presence (POP) providing onboard data processing, data storage, and routing via optical-to-optical, optical-to-RF and optical-to-copper communication links through the satellite(s) and/or flat-sat. To insure interoperability with terrestrial systems, standard optical telecommunications protocols and standards would be implemented.
3. Ka-band high rate RF terminal for satellite communications to evaluate the performance of hybrid FSO/RF communications networks inclusive of testing:
    a. A Ka-band space to ground links for real time switching between Optical and RF networks (transceivers)
    b. Ka-band/FSO networking and data failover techniques, and

    c. Interoperability between various satellite network architectures with FSO and RF link capabilities

4. S-band low rate RF terminal for satellite communications to establish command and control and data handling (C&DH) of the optical payloads to enable testing of OGSs. The optical payload could be commanded either through the RF or the optical SGLs. Approaches to convey information regarding ephemeris, pointing angles and scheduled access times with optical relays could be tested.

5. Network architectures to incorporate non-secure and secure (Red/Black) data transmissions including the separation of non-sensitive and sensitive data for both government and commercial data links. Such capabilities and testing will be critical to US Government and Military communications.

6. OCP/Flat-sat: The elements of a NASA defined space segment optical module below could be built in the form of an integrated terminal mounted on the mast, or in the form of a flat-sat. The terminal would consist of the basic building blocks (modules) of an OCP and enable testing of OCPs with OGSs.

7. Environmental Data Collection Station and Cognitive Network: In order to capture environmental conditions existing at the time of each test, a compliment of environmental data collection equipment might be included. Mitigation techniques such as dynamically switching optical and RF links based on predicted performance could be tested.

8. Cognitive Network Testing: With the TOP-POP equipped to provide real-time weather data, cognitive networks designed to self-configure links and assign assets based on reliability predictions could be tested. Such techniques take advantage of the site (geographic) diversity of optical and RF terminals to dynamically reroute data traffic to achieve optimal efficiency in the data transmission and avoid data loss due to atmospheric conditions. A variety of potential network models exist to optimize the routing of data traffic. Such techniques compliment the physical layer in modulation, coding, adaptive optics and PAT. A mobile test platform would facilitate the development and testing of these approaches.

9. Test Measurement and Diagnostic Equipment (TMDE) to be defined by final objectives.

The TOP-POP test bed would provide NASA and industry partners a test platform that accommodates industry partner provided transportable and stationary OGSs to operate in conjunction with high rate Ka-band and S-band terminals for satellite communications and satellite command and control, and on-board network architecture providing both local area networks and Wide Area Networks. The TOP-POP would enable the testing of a wide variety of industry OST and OGS solutions. A conceptual representation of the TOP-POP trailer is presented in Figure 1 below.

Figure 1. Potential Configuration of TOP-POP Trailer, Curb-side View

V. CONCLUSION

The application of free space optical technology to satellite networks will generate significant improvements in the performance of satellite communications. While optical technology is well developed, its evaluation in real-world satellite network scenarios is limited. A plethora of techniques are available to mitigate the effects of adverse environmental conditions and facilitate the efficiency of FSO transmissions; however, it is not certain which combination of those techniques are optimal. Further development and testing are required.

In addition to the testing of potential design concepts such as the selection of wavelength, PAT methods, synchronization, modulation, aperture size, spatial diversity, coding, transport layer, adaptive optics, etc., the testing of network management techniques such as site diversity, cognitive diversity networks, hybrid RF/FSO networks, data security and QoS must also be developed and evaluated. To do so, a test platform capable of interfacing with NASA and US industry OSTs and OGSs is required.

As most optical ground stations are stationary, a transportable test platform is necessary to bring the test bed to the terminals. Additionally, as testing should occur in a variety of environmental conditions (i.e. geographic locations, weather, etc.), a transportable test platform is required to place the test platform in varying environmental conditions.

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