Satellite based Substation Communications

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Abstract – *Experiments were conducted at an electrical substation to ascertain if a low-earth-orbiting (LEO) satellite communications network could be used for measurement and control in such a setting. Results are presented.*

Key Words: electric grid, substations, satellite communications

1. INTRODUCTION

The use of satellite-based communications for utility applications has been investigated for decades [1-4]. The network designs have sometimes relied on satellites in geosynchronous orbit (GEO), medium earth orbit (MEO), or low earth orbit (LEO) with several hybrid variations (Fig.1). A variety of applications have been considered and in some instances demonstrated [5,6]. Frequently the latencies associated with up/down communications to GEO satallites precludes their use in applications requiring quick response such as Emergency Management and Supervisory Control and Data Acquisition (SCADA) systems [7].

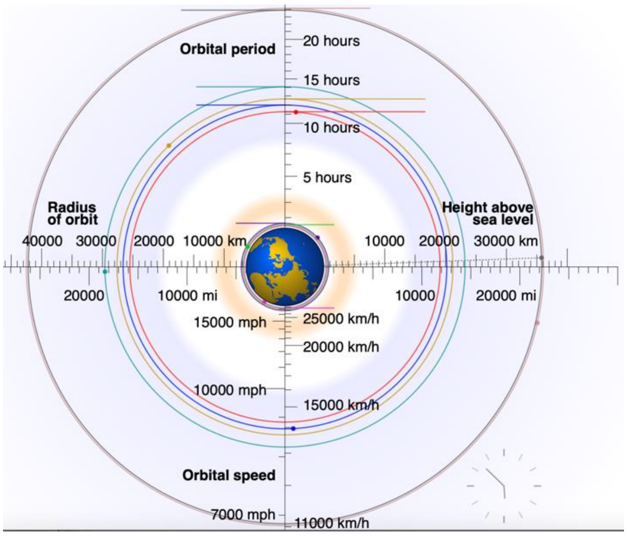

Fig.1. Various earth-centered communication satellite orbits.

The information transfer needs associated with an electrical substation differ from those associated with standard IT operation primarily due to the necessity to meet all latency requirements for grid operations. Control commands must arrive at the substation within certain latency bounds with associated operational targets set for the grid measurements to be transported from sensor to the utility's supervisory control and data acquisition (SCADA) system. Table 1 presents such latency requirements for various grid operations. Note that the associated required bandwidth is not listed. This is due to

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the requiring bandwidths being in the approximately 1 Mbps range with associated small packets of information being exchanged[1].

Application (only a few example applications considered)	Application setting		Latency allowance (assumed, unverified)	Comments
Teleprotection	All	← In the order of decreasing priority	8 ms, 10 ms	For 60 Hz and 50 Hz, respectively
Phase measurement unit	Class A data service		16 ms	60 messages per second stipulated for Class A data service in [14]
Push-to-talk signaling	Incident-related		100 ms	
Smart meter	Connect to many meters in a short time		200 ms	Example: ADR within 1 minute for up to 300 meters connected over a shared medium
SCADA data: poll response			200 ms	See [8].
VoIP bearer			175–200 ms	Includes P2P and all PTT
VoIP signaling			200 ms	Includes non-incident-related PTT
Phase measurement unit	Class C data service		500 ms	Post event (latency value assumed). See [14].
On demand SCADA			1 second	See [8].
Smart meter	Periodic meter reading		≥ 1 second	Say, once an hour or lower frequency of reading

ADR—Automated demand response
P2P—Peer-to-peer
PTT—Push-to-talk
SCADA—Supervisory control and data acquisition
VoIP—Voice over IP

Table 1: Latency requirements for the enhanced grid architecture [1].

While most electrical substations rely on system communications based on wired, wireless or optical, the deployment of large low earth orbiting communications networks (e.g., StarLink, OneWeb, OrbComm) makes the use of such satellite-based substation communications worthwhile to investigate. We conducted near proximity, in-field performance testing of a Starlink system at an electrical substation.

2. Orbital Dynamics and Communications Coverage

Geosynchronous orbit provides a constant coverage pattern (on the planet) allowing for fixed terrestrial antenna placement and alignment. This situation leads to operation where the aforementioned signal latency becomes a limiting factor in use. An alternative situation arises in the use of a network LEO satellites where they must be placed into an orbital configuration where the communication signals will not only be the conventional up/down variety - with shorter distances between ground and satellite, hence lower latencies - but also in motion (orbiting). The last point leads to deploying a mesh of satellites operating in a coordinated manner such that as one LEO works its way out of the terrestrial antenna's field of view with the communications "messages" then handed off to the next LEO satellite coming into the ground antenna's field of view. The "hand off" situation is similar to that encountered as a mobile/cellular telephone seamlessly hands off from one cellular tower to the next[2]. Again, similar to the cellular phone system where the planet is divided into cellular coverage areas (towers with broadcast/reception zones), in the LEO satellite communications case, the planet is also divided into an array of hexaagonal coverage zones. This situation for the Starlink system is shown in Figure 2. Note that the operational satellite constellation (as of October 2021) is configured in a manner that does not provide coverage of the far north.

[1] The exception to this lies in the use of video cameras in substation settings. The bandwidth required for video camera image transfer varies widely based on parameters such a image size, resolution, frame rate, etc. General values may be estimated with an approximate upper bound associated with a single IP cloud camera's typical average bandwidth requirement of 1-2 Mbps.

[2] Note that in the cellular phone case the towers are at a fixed location and the phone is moving, while in the LEO "situation" the satellite is moving and the utility substation is at a fixed location.

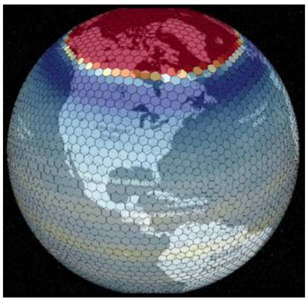

Fig. 2: The earth is organized as a hexagonal grid.

Figure 3 presents an increasingly finer scale depiction of the Starlink coverage map with respect to the electrical substation where the performance measurements were made (east Tennessee, USA).

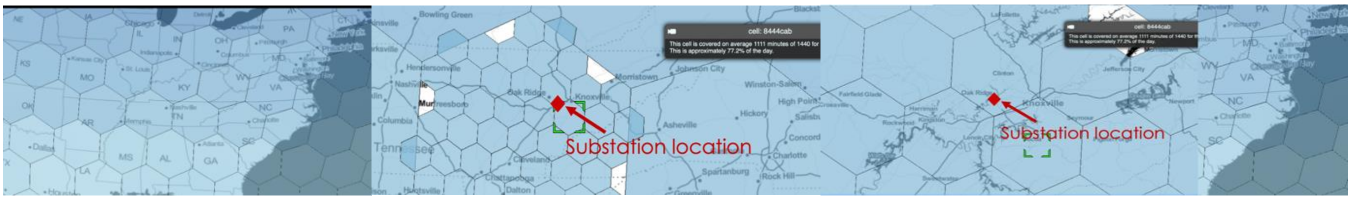

Fig. 3: Increasingly finer scale hexagonal coverage zones.

The satellite constellation and its associated orbital dynamics provide discriminated global coverage bidirectional communications. With over 1,600 satellites[3] on orbit (as of October 2021) in differing orbital planes, this results in a high probability of up/down communications between the satellite transceiver and the companion ground transceiver (in our case, at the utility substation) throughout the world. Screenshots of the satellites on-orbit above North America and EurAsia are shown in Figues 4a and 4b[4].

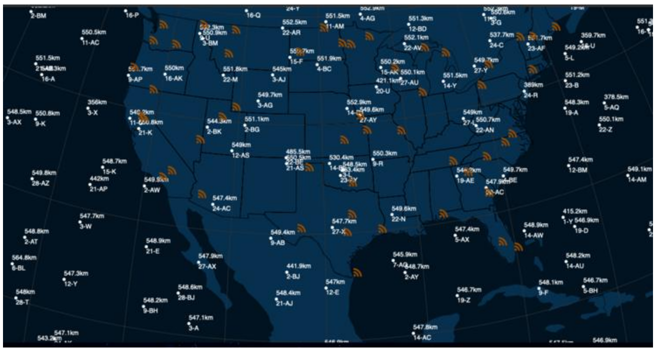

Fig. 4.a: Screenshot of the Starlink satellite constellation over North America..

[Source: https://satellitemap.space/#]

Fig. 4.b: Screenshot of the Starlink satellite constellation. over EurAsia. [Source: https://satellitemap.space/#]

3. MEASUREMENTS

While not an exact depiction of the equipment layout configuration at the substation where the satellite performance was measured a representative view of energy flow - and associated equipment - for a generic substation is presented as Figure 5. Visible and thermal images of a section of the substations where measurements were taken are shown in Figure 6.

[3] out of a planned 32,000 satellites [8].

[4] Note that these satellites are in motion, making this screencapture representative of the constellation at the time of this capture.

Fig. *5:* Energy flow in a generic electrical substation.

Fig. 6: Visible and IR photographs of a section of the electrical substation.

Spectrum analyzer measurements of the ambient radio frequency (RF) background - 9kHz to 3 GHz frequency range - are shown in Figure 7. The measurements were taken using an Owon XSA1036-TG spectrum analyzer. The prominent signals were at 1.715, 1.855 and 2.410 GHz. The first two signals are associated with cellular Long Term Evolution (LTE) broadcasts. The signal at 2.410 GHz is in the Industrial, Scientific and Medical (ISM) license free band.[5]

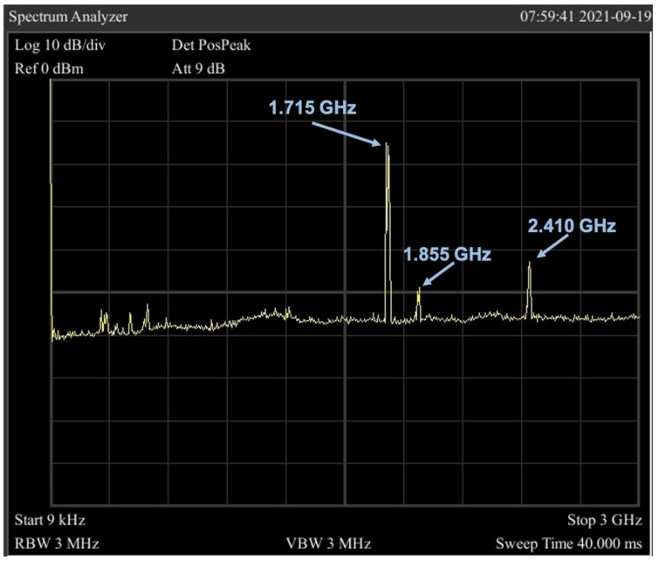

Fig. 7: Ambient RF environment at the substation.

A photograph of the configuration used for performance measurements is shown in Figure 8.

Fig. 8: Starlink transceiver deployed at utility substation.

Of primary interest regarding potential use of a Starlink system for transport of substation measurements and SCADA information were the bandwidth, latency and network outages. All measurements used an application running on an iPhone 7 which was connected to the Starlink modem ("base station") via Wi-Fi. A speed test using the web resource Fast.com was conducted. The asymmetric upload/download speeds measured are shown in Figure 9.

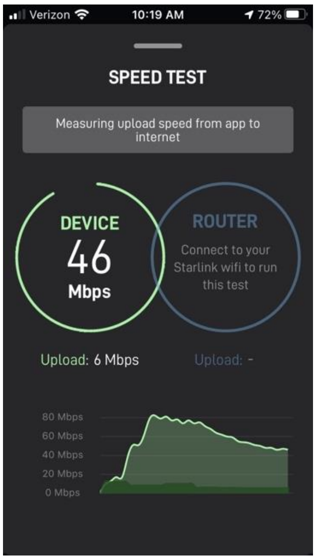

Fig. 9: Results of speed test conducted at the substation.

Similarly, latency and outage tests were performed using the same connection and software configuration as that used in the speed test. Results are shown in Figure 10.

[5] the (nominal) 2.4 GHz ISM band is used by a variety of wireless applications including Wi-FI and Bluetooth.

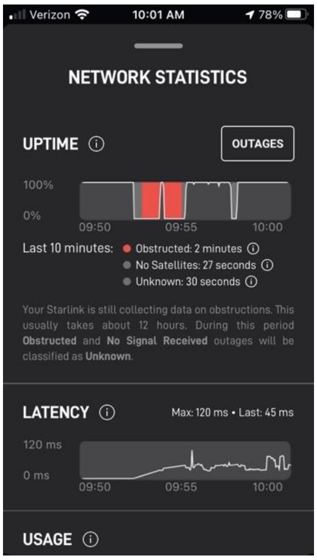

Fig. 10: Latency and network outage test results.

The variability in latency, as measured, ranging from 45 to 120 milliseconds coupled with the network outages - while few - detected during 10 minute intervals exemplifies that the Starlink system is not reliable enough for critical substation communications. It is anticipated that the performance will continue to improve as the number and location of satellites increases.

4. CONCLUSIONS

The utilization of satellite-based communications as the transport technology to support electric utility system operations has entered into a different consideration domain principally due to the deployment of large scale LEO-based wireless networks. Such networks offer large coverage areas with performance that meets an array of utility application needs. Such needs for the fully integrated modern grid are exemplifed in Figure 11. The performance investigation described in this paper should serve as an introductory baseline for utility consideration. As the satellite constellations increase in number and coverage areas they may become of acceptable reliability to serve as, if not the primary means for communications with remote substations, then perhaps as a redundant system.

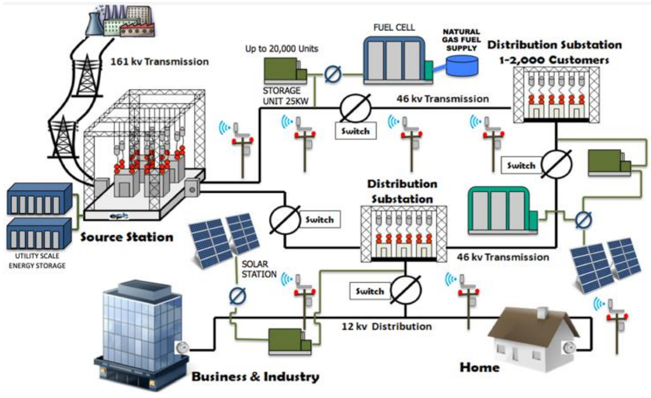

Fig. 11: Components of the modern electric grid.

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