# County Information Services, LLC
# Confidential Materials in Support of
# WN2XCR Renewal

## 1. PART 90 RULEMAKING EFFORTS

County Information Services, LLC ("CIS"), a subsidiary of the Optiver Group, has been engaged in rulemaking efforts to create an authorization for commercial HF data-link systems with experimental licensees under part 5. Most recently, CIS has been a founding member of the Shortwave Modernization Coalition. The focus of the Coalition has been the development of technical analysis, policy, and appropriate rule changes or waivers under part 90. With the grant of this application, CIS will continue testing and adjusting the technology it has developed with the progression of rulemaking. *See* R.M 11953.

## 2. EXPERIMENTATION AND DEVELOPMENTS UNDER OET AUTHORIZATION

After initial authorization in 2015, work began on the detailed design and build of hardware, software, and sites. By February 2017 our prototype transmitter was on the air. By November of the same year, we began sending data.

Transmit Station

- Developed an understanding of terrain & environmental requirements for HF

  As part of transmit site and Transmit Station development, we have researched and developed technical requirements and guidelines for the area and terrain surrounding a high-powered HF transmit station. Regarding the environmental specifications for our own transmit station, we have set up site safety and EMC requirements. Using EM field modeling, we have determined the access restriction policies for transmitter station (TX) safety and EMC compliance. For terrain requirements, we have introduced the concept of a Fresnel Zone footprint and have developed requirements for the terrain properties inside this footprint. Terrain requirements are needed for a HF antenna to operate as intended because of the large interaction between the antenna and its surrounding terrain. Our tests at the Wanatah, Indiana site have so far confirmed our models. However, more work is needed to verify these results while using multiple antenna systems, frequencies, and beam directions.

- Development of a prototype transmitter @ 1kW (2015 - Nov 2017)

  In the period from early 2015 until Feb 2017, we designed, built and field tested an HF transmitter prototype with 1 kW max output power, covering a limited frequency range and meeting the technical requirements of Part 90 for meeting mask C. This prototype was used February 2017 – November 2017 at our transmit site, utilizing our own transmit antenna system and a temporary experimental receive site in Europe. We gathered initial HF propagation data by sending several test patterns at varying data rates.

- Development and experimental operation of 10kW transmitter 2016 - 2017

  In parallel to testing the small-scale temporary 1 kW prototype transmitter, we have designed and built a large-scale (10 kW max transmit power) version, covering a wider frequency range and meeting the technical requirements of Part 90. This transmitter uses our ground-up designed and built modular amplifiers and is remotely controllable. It also uses fully integrated tunable filter sections for spectral mask compliance and the Antenna Tuning Unit. After completing the installation in the Transmit station in November 2017, we started our HF radio link experiments using this transmitter.

- Design, optimize, and field test customized LPDA antennas

  As part of the experimental HF transmit station development, we have designed and built a log-periodic antenna array, customized and optimized for long-distance point-to-point HF links within a limited frequency range. An extensive design, modeling, and field-testing trajectory led to the realization of an LPDA array that has a directivity close to the theoretically achievable maximum for these antenna types. This development was not limited to the design of the LPDA antennas, but extended to the optimization of the Transmit station array set-up, to match peak directivity to the range of take-off angles (T.O.A.) required for a long-distance HF link. As part of this antenna design process, we have also developed a method to measure the real peak gain and directivity of the antenna system.

- Robustness improvements of the transmitter

  The developed HF transmitter contains servo-controlled, mechanically adjustable inductors and capacitors, to tune the integrated high-power filter sections to the center frequency of the TX channel being used. Various mechanical and electrical problems with the initial version of adjustable inductor set-ups led to several long-lasting outages and interruptions of the HF propagation experiments. As a result, we made several improvements to the filter sections, including a change in the type of insulating couplers and clutches (2018) and eventually a change in the type of inductors inside the high-power filter sections (2019). These modifications resolved serious reliability problems we had with the filter sections and they have proven to be very robust since then.

- Development of remote monitoring and control systems

  The HF transmitter is operated and controlled from sites several hundreds of miles away. As such, CIS developed a wide-ranging set of software systems to remotely monitor and control the transmitter and site facilities. These include monitoring and control of; the station's RF source, antenna reflected power, fine-tuning matching circuits, RF output power limiting feedback, antenna switching unit changes, tuning parameters, power ramp-up characteristics, station ID, and the development/integration of relays for emergency shutdown.

Propagation Study

- 11-year solar cycle – impact and mitigation studies

  HF radio link experiments began in 2017, at the end of Solar cycle 24, a period of low sunspot numbers and a quiet, relatively stable ionosphere. Since early 2022, we observed a change in the ionosphere's behavior associated with increased solar activity due to the onset of Solar cycle 25. So far, the changes observed in the ionosphere are higher peak intensity, decreasing stability, and more turbulent and frequent disturbances. We believe these solar cycle effects impact our HF link operational models. We aim to continue our experiment during the growing/peak phase of the solar cycle. This would enable us to further optimize our operational model and develop a HF radio link that supports the different phases of a solar cycle.

- Seasonal effects

  Based on our HF radio link experiments over the course of several years, we observed typical characteristics of ionospheric propagation during different seasons. We especially characterized significant differences between Winter and Summer HF radio propagation. During these years, we also developed a good understanding of the background of the seasonal characteristics we observed and analyzed. This knowledge gives us the ability to better predict and optimize link reliability and parameters for upcoming seasons.

- Sporadic-E: Characterization, mitigation tactics, and need for testing

  After having observed a structural degradation to HF radio link quality during each (late) Spring and Summer season in 2017-2018, we started investigating the cause. By including real-time monitoring data from HF ionosondes in the USA and the UK, we discovered a strong correlation between link quality degradation and the presence of Sporadic-E. After gathering and analyzing sufficient measurement data, we concluded that Sporadic-E was/is indeed the cause of this cyclic degradation. In the period after, we developed more knowledge about the background of Sporadic-E and better understood how it deteriorates HF radio link quality. We concluded that the strategies we use to mitigate other causes of HF link degradation do not effectively mitigate sporadic-E. We therefore developed a few new concepts for sporadic-E mitigation that we have not yet been able to implement and test. For that, we would need additional time provided by this license renewal.

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- Multipath effects & mitigation strategies

  During our initial experimental period, we extensively analyzed the quality and reliability of the HF radio link. We concluded that multipath interference is the main bottleneck to achieving high link reliability. We investigated various causes of HF multipath interference, such as multi-hop interference, high/low ray interference and O/X ray interference. Based on the knowledge we gained about these multipath phenomena, we developed and extensively experimented with a concept based on real-time, optimal frequency selection. Using this strategy, we effectively mitigated some multipath sources. Next to this strategy, we still have other concepts to further mitigate multipath (together with sporadic-E mitigation).

- Polarization fading study & impact analysis

  As part of our HF radio propagation experiments, we investigated the impact of polarization fading on HF link reliability. We investigated the Faraday effect on ionospheric propagation and how it impacts our HF radio link. We also developed a concept for a polarization diversity set-up, and we analyzed its improvement to link quality. We concluded from this study that polarization fading is not significantly impacting the link reliability and therefore decided to not continue with the setup.

- Check the correlation between models and reality

  Before the HF radio link experimental period, we completed a series of simulations using VOACAP-based HF link modeling and prediction tools. Using these tools, we tried to predict various link parameters, such as reliability and optimal frequency, for all operating hours and seasons, based on models of our Transmit and Receive stations. During the experimental period, we regularly compared (and still compare) modeling results and predictions with the daily reality of the HF radio link. From that, we could draw conclusions on the correlation between modeling and reality for several aspects and parameters of the radio link. We recently performed additional simulations for HF link extensions in other directions and extended operating hours. During the additional experimental time, we can start comparing these modeling results with reality.

Application-level messaging and transport efforts

- Data selection/triage

  An algorithm has been developed which detects changes in information in one marketplace, codifies this data, and then automatically selects a queue priority to send the information via the HF link. The queue priority is determined by a set of user-controlled parameters. The data is later analyzed for timeliness, accuracy, and overall pertinence.

- Message classifications & SNR

  Messages arriving at the Receive station have wildly varying quality as indicated by SNR, RSSI, and a bit confidence score applied by the demodulator which the company has developed. A message classification system then determines a score for each received message. Some messages meet the classification of highly actionable information, and other messages meet a lower boundary and are used to temporarily stop user's activity. Over the course of testing in the last period, this has been further optimized to remove RSSI as a stop-gap parameter for avoiding false positives.

- Codeword development, optimization, and integration

  A special codebook of 256 different codeword combinations was developed to represent information events. Empirical research has shown that some codewords had an increased proclivity for so-called 'bit-flips'. A method for identifying these bit-flip events and banning certain codewords was developed. Codewords and their definitions are maintained by end users. Thus, a whole ecosystem of software was developed to control, monitor, and change the codebook and the applications utilizing it.Further changes to the packet structure of our messages are also under consideration. These modifications could improve how well we handle ionospheric distortions, which we've found don't align with traditional Additive White Gaussian Noise (AWGN) channel-based design techniques due to the high time distortion present in the ionosphere. As a result, Hamming Distance, typically used as a reliability indicator, isn't as effective in this environment. This has pushed us to rethink our approach to error correction and packet design to better suit the unique challenges of HF channels.

Receive Station

- Research Receive station requirements (terrain, environment)

  We developed sets of requirements for receive station selection on flat terrain. These requirements are largely defined by acceptable low ambient noise levels and specific terrain properties which engender minimized interaction with the antenna array. Requirements were used to guide optimal terrain and urbanization characteristics in site selection processes.

- Develop a noise & interference measurement setup

  To verify if a potential receive site would qualify, an ambient noise and interference measurement setup was designed, built, and calibrated. This portable setup allows us to check a potential site in the field, determine potential noise and interference sources, and check for mitigations.

- Receive array design & optimization

  CIS developed a novel active antenna array that can be deployed quickly and inexpensively, even in highly restricted zoning areas. The array consists of 8 or more active monopoles, not more than 7 feet off the ground.

- Low-noise, low-power receive site front-end

  Many receive stations are placed in rural locations without access to grid power.. A low-power, low-noise receiver front-end was developed, built, and tested in the field.

- Selection, and integration of a low-noise power system

  With no access to grid power, and to reduce maintenance, lower fire risk, and keep noise levels extremely low, a fuel cell was deployed and integrated into the existing technology platform. Several software-based tools were developed to control and monitor power and its consumption at the site.

- Develop design and engineering knowledge of low noise RX sites

  Because of the strict requirements for the ambient noise level at an HF RX site, during the experimental period, a methodology was developed for the design and build-out of HF Receive sites with an extremely low noise floor. This methodology must prevent the active equipment of the Receive site from generating noise and interference that would degrade the effective sensitivity of the RF chain. The methodology consists of a series of design and engineering practices around shielding, filtering, and grounding to prevent noise from being generated and picked up by the Receive site RF chain

MODEM

Several improvements were investigated and tested to improve the overall reliability of the system.

- Improved control loops to affect link quality
- Modified modem for multiple bit-rates
- Modified modem for use with multiple receiver types/IQ data formats

  Our analysis of the real-time behavior of our current GMSK MODEM through both real and challenging propagation conditions allowed us to develop a new concept for the architecture of an improved MODEM and concomitant requirements for an ideal modulation scheme.

Link Operations

- Bit rate changes

  Development and implementation of a method to detect the necessity for bit-rate changes and apply them.

- Spectrum monitoring & interference mitigation

  Software was developed to check power-in-band changes in the current center frequency and over the next available 10 center frequencies. This information is used by software and operators to determine interference risk and to recommend new channels.

- Channel selection automation

  Using a set of rule-based parameters derived from propagation studies along with interference checks of power-in-band in nearby channels, the Company has built a channel selection tool to automatically determine the best available channel. Changes to the solar cycle this year have largely negated the rules-based system, necessitating further studies.

- Transmit power study (<10kW)

  CIS has continually experimented with lowering output power to determine a minimum viable boundary under different conditions. Further studies and operational models will later be developed to implement a system capable of automatically reducing the output power depending on conditions.

- Non-mechanical harmonic suppression/channel filtering techniques

  CIS began development of new techniques for harmonic suppression/channel filtering at high power. This has enabled the company to remove some mechanical coils, in certain frequencies (14.24Mhz) but development work has not completed.

- Frequency range improvements and multi-channel operations

  Widening the available transmit frequencies of the system from 13-20MHz to 7.457-24MHz.

  Beginning in July 2023 CIS was able to test analyze RF co-existence of a multiple transmission, single site setup.

  CIS has extended the range of transmit frequencies and sites to run its experiments 24 hours per day but has not been able automate its systems.

- Framing techniques and demodulator improvements

  CIS investigated changes to the 'idle pattern' it uses to lock its demodulator, reduction of payload and framing sizes, and methods to utilize the idle pattern in certain matching cases as the pre-amble. This work resulted in significant latency improvements. In addition to these enhancements, we've also implemented a live-running BER (Bit Error Rate) calculator based on the idle pattern. This allows for continuous, real-time reliability metrics, which can be monitored during periods of low link activity when timing-critical signals are not being sent through. Looking ahead, a further improvement could involve expanding this technique to allow continuous time-of-flight measurements, enabling us to profile latency independent of sent messages.

  Future improvements will also include live channel state information (CSI) logging, similar to how we expose BER. This would allow us to estimate both the latency and the reliability of the channel in real time, providing a more comprehensive understanding of channel dynamics.

## 3. PLANS NECESSITATING A RENEWAL

- System and operational changes resulting from rulemaking activities

- Automation of system interface, control, and monitoring

  The existing local and remote-control panels can only be accessed facility-wide by one user at a time. To move the technology to a multi-user and multi-frequency paradigm several fundamental changes to the transmitter firmware and monitoring systems are needed.

- Simplify signal generation and modulation chain

  The current signal generation and modulation chain utilizes a specialized interface between the modulator output and the exciter input. The chain can be modified to remove this interface box with some further development. The interface is a source of maintenance/reliability issues and propagation delay.

- Frequency diversity techniques

  The expected low correlation between the signal quality of two channels, spaced far enough apart, can be used to improve the overall link reliability by as much as 20 percent. By demodulating and decoding the received signal of both channels in parallel, the instantaneous signal quality (SNR/MSE) and received data of both channels is measured, time-stamped, decoded, and logged. An analysis will determine the correlation between the signal qualities. The lower the correlation, the higher the achievable improvement will be. This measurement process will have to be repeated with different spacings between the two channel frequencies, until the minimum spacing, yielding the lowest plausible correlation, has been found.

  For the frequency diversity experiments, a significant modification to the transmit station would have to be necessary. To transmit on at least two channels in parallel, identical transmitters would have to be built, sharing the antenna systems. Although this has largely concluded, we still aim to build the automation and control systems necessary to achieve sustained higher reliability.

- Receiver Diversity techniques study

  CIS plans to conduct regional space diversity investigations over two distant areas with widely varying propagation conditions (Europe and Asia). Multiple receiver-diversity setups within each region will help the company research and develop different receiver space diversity setups using a single transmission site. By demodulating and decoding the received signal at multiple locations in parallel, two streams of decoded test messages would be obtained. When an added receive site has been set up at a certain location, the instantaneous signal quality (SNR/MSE) must be measured, time-stamped, and logged at interval times of less than 1 second at both receive locations. In parallel, at both locations, the received test data also must be decoded, time-stamped, and logged. The logged data of both sites will be analyzed to determine the correlation between the signal quality at both sites. It is expected that the lower the correlation, the higher the achievable improvement will be. Comparing the received and decoded test data streams of both sites, during a specific period directly shows the increase in effective link reliability. To achieve low correlation, this measurement process for the diversity receive site will have to be repeated at several different locations around the main receive site until the minimum distance between the receive sites has been found.

  In addition, we are planning to expand this approach by incorporating receiver antenna diversity and spatial signal processing. Currently, we use a fixed beamformer on our antenna array, but we plan to separately sample each antenna in the future. This will allow us to investigate the correlation between antennas and explore how receiver antenna diversity can help with multipath separation and spatial channel equalization.

  Beyond spatial channel equalization, we also plan to use spatial processing to reduce environmental noise through noise cancellation algorithms and to improve interference cancellation.

- Channel Sounding

  Over the course of other work the company has seen a clear need for channel sounding experiments to drive signal processing innovations.

  The goal of this campaign is to characterize HF multipath channel propagation between our transmitter and receiver sites. We aim to measure the channel over time, elevation angle, and doppler effects. This will help us create channel models and refine signal processing parameters, leading to better decisions around modulation,, system design, and operational considerations.

## 4. MODULATION AND EMISSIONS

CIS will continue to utilize GMSK modulation as specified in prior applications, ensuring emissions remain firmly within its authorized bandwidth and maintaining compliance with FCC Part 90 mask (C) limits when the occupied bandwidth and modulation matches Mask C specifications. Additionally, a range of other modulation parameters may involve deviations from FCC Part 90 mask (C) compliance. These experiments are conducted in line with the Shortwave Modernization Coalition's efforts to petition for rulemaking changes at the FCC, and channel sounding efforts.

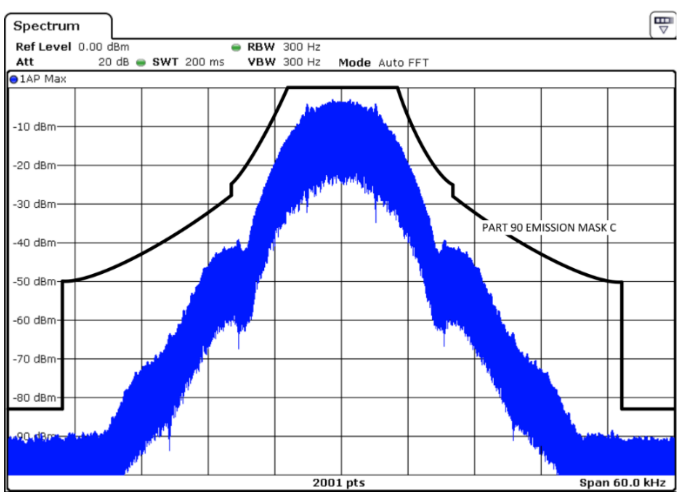


FIGURE 1