Optimal Signal Design for Joint Radar and Communications Systems

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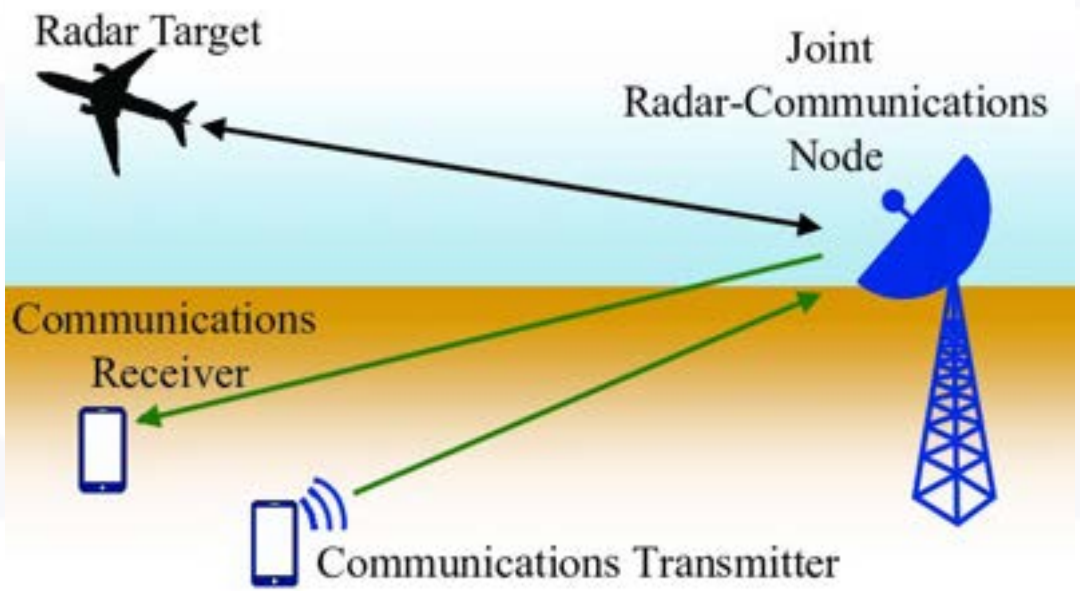
Introduction:

- RADARCOMM is joint radar and communications research/technology
- Achieved through 2 main approaches
  - Signal modification for coexistence
    - Modify signal properties to promote coexistence with other signals
  - Signal design for dual capability
    - Design singular waveform capable of performing both tasks
- Multiple benefits from RADARCOMM implementation
  - Increased efficiency of bandwidth usage
  - Reduced interference from clutter

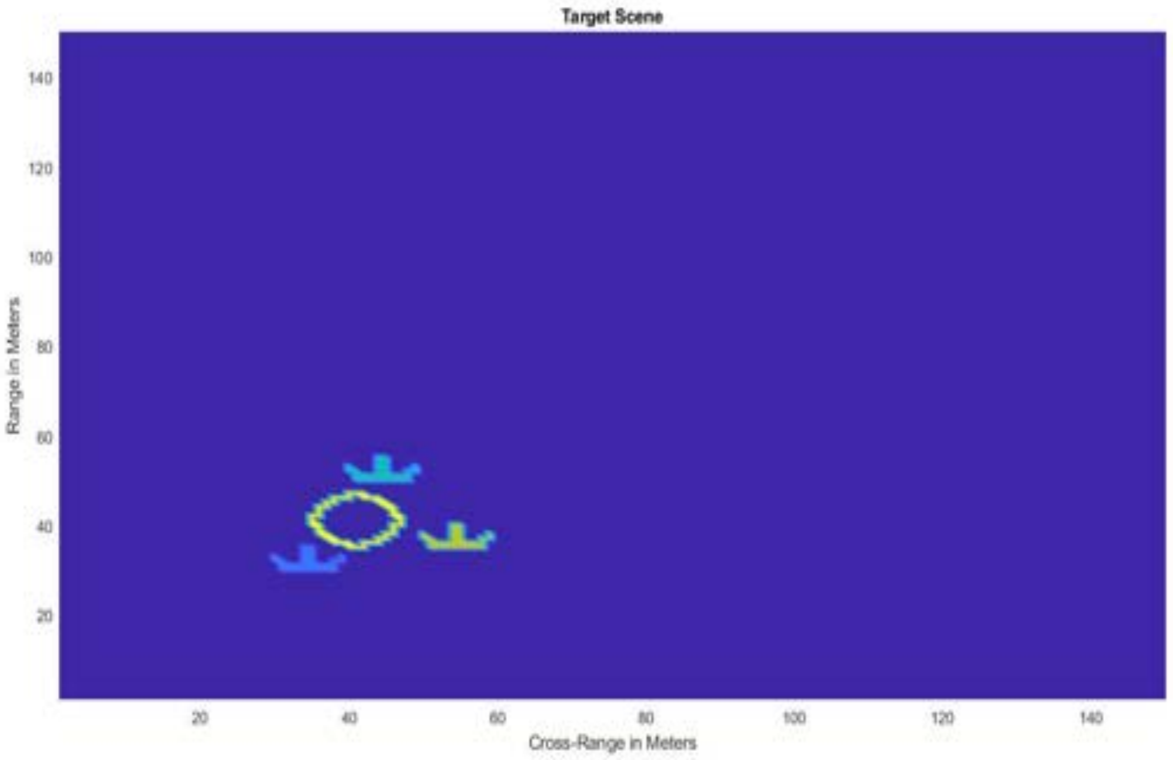


Our Methodology:

- Focuses on signal design for dual capability
- Developed a simulation of a Synthetic-Aperture Radar (SAR) scenario for analysis of RADARCOMM signals
- Analyzed several common communications signals for feasibility as RADARCOMM signals
- Experimentally determined pseudo-random chaotic signals and Orthogonal-Frequency Division Multiplexed (OFDM) signals to be viable for RADARCOMM applications
- Identified unique properties advantageous for SAR scenarios for each signal
- Developed original pseudo-random coding scheme for OFDM signal to increase communications security

Simulation Overview:

- SAR simulation utilized to test performance of communication signals in radar scenario
  - Compared to performance of standard radar LFM Chirp
- 150m x 150m target scene containing targets of varying size, shape and reflectivity (between 1 and 0.4)
- “Stop-and-Go” procedure utilized to image the scene
  - Radar platform traverses bottom of the scene, stops at a point, transmits the signal, receives its reflection then moves to the next point
  - 50 cross range points used
- Scene imaged under varying noise levels (20dB to -20dB)



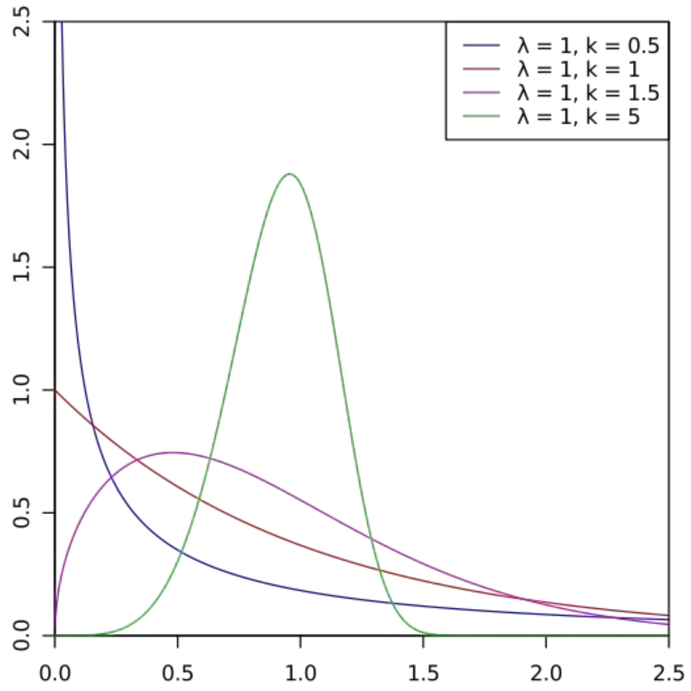
Signal Design Overview:

- Utilized chaotic signal design outlined in C. S. Pappu and T. L. Carroll, "Chaotic waveform for optimal joint radar communication systems," Chaos, Solitons & Fractals, vol. 169, p. 113261, 2023.
- Standard OFDM signal utilized with 512 subcarriers
- Random Sequence Encoding (RSE) utilized for OFDM subcarriers
  - Uses samples of random distribution to encode communication data
  - Data recovery requires simple linear calculation for authorized receivers
  - Complex non-linear calculation required for unauthorized receivers
- Both signals simulated at bandwidths of 100 MHz, 1 GHz and 10 GHz
- Signal energies are equalized to ensure fair comparison

Random Sequence Encoding (RSE):

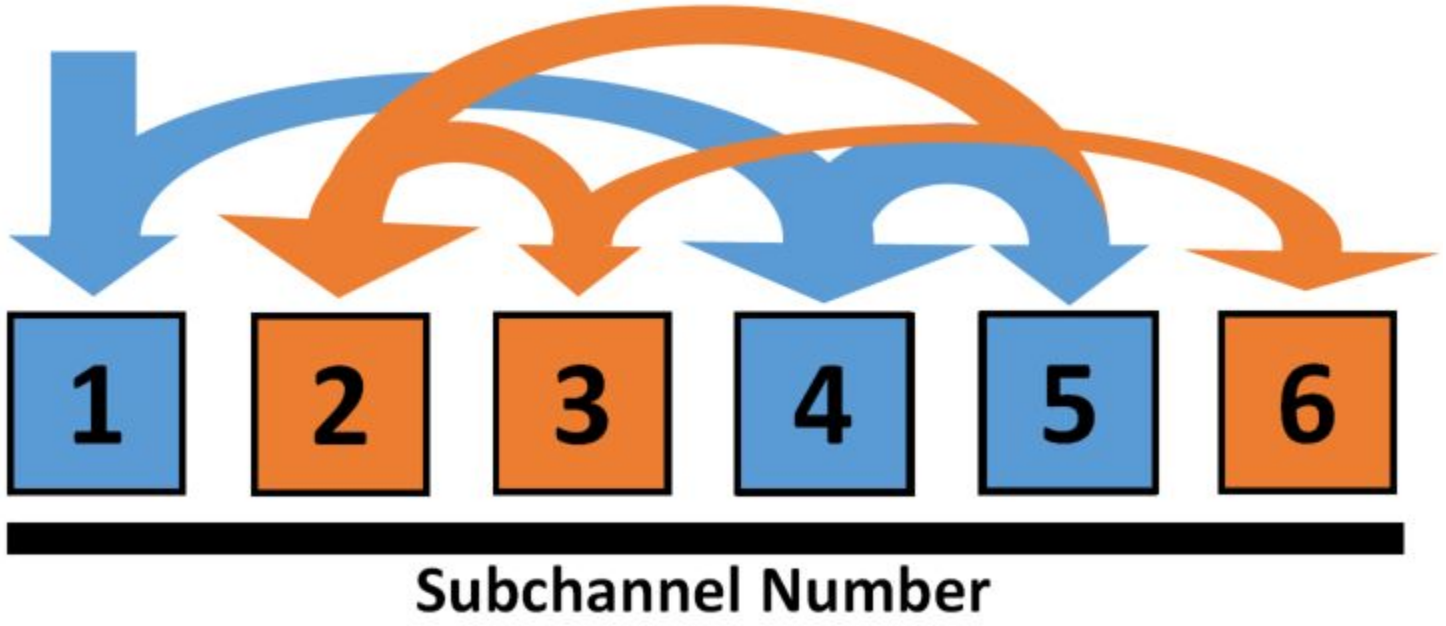
- Method of encoding multi-carrier signals (OFDM signal with 512 subcarriers for this research)
- Generate samples of random distribution equal to number of subcarriers
  - Weibull distribution used here, characterized by scale parameter λ (contains data to be transmitted) and known shape parameter k
- Assign samples to subchannels and transmit
- Reconstruct λ (the data) at the receiver using the transmitted samples $E[\hat{S}]$ and known k:

$$\hat{\lambda} = \frac{E\left[\hat{S}\right]}{\Gamma\left(1+\frac{1}{k}\right)}$$



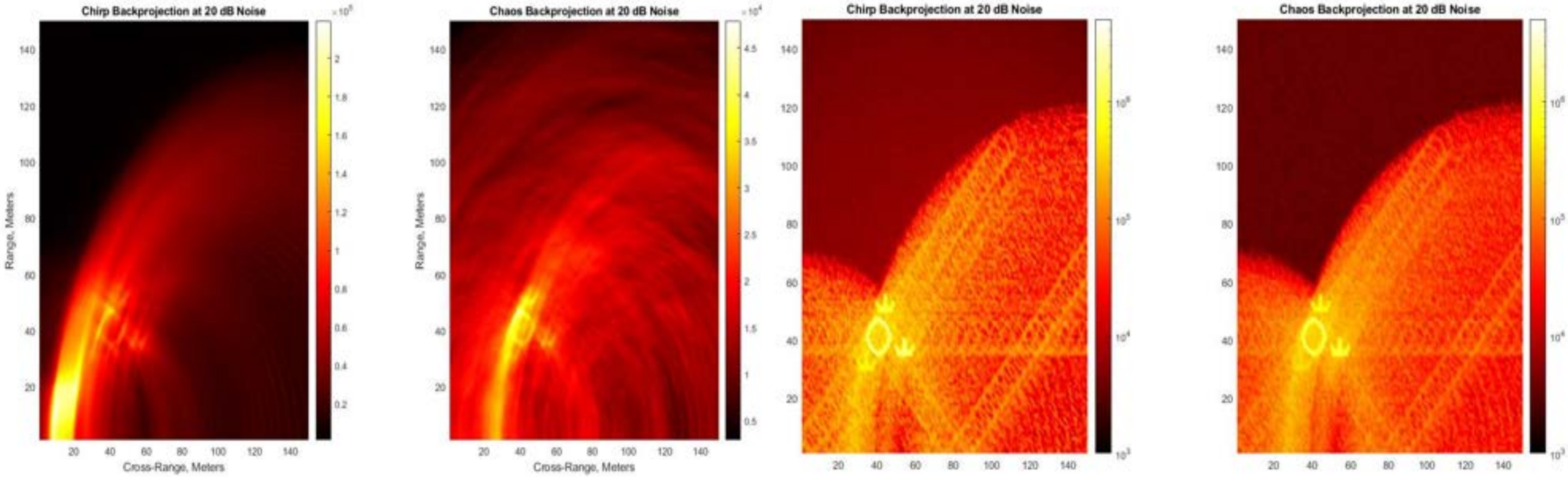
OFDM Signal Secure Encoding:

- Developed randomized method of channel encoding for increased communications security in OFDM signal
- Utilizing seed known to the transmitter and receiver, random distribution samples are pseudo-randomly assigned OFDM subchannels
- Greatest security achieved through additional “signal interleaving”
  - Multiple unique distributions generated and randomly assigned subchannels in same OFDM signal



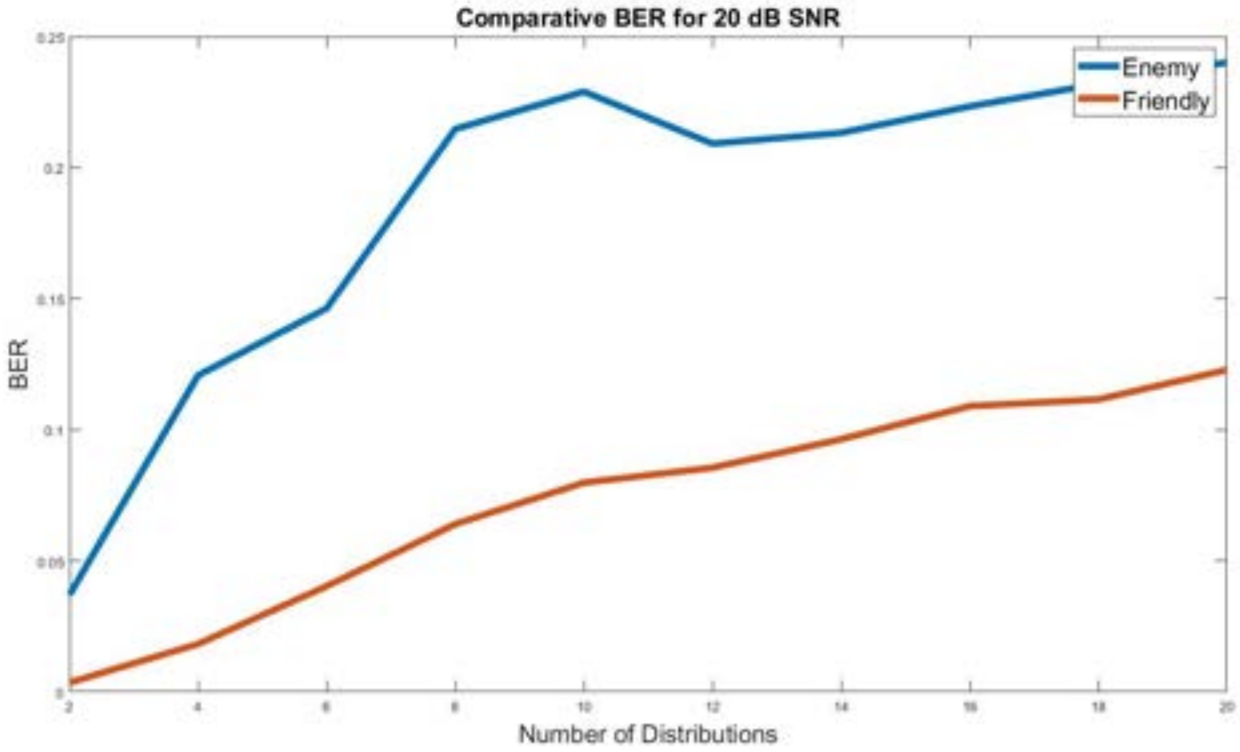
Chaotic Signal Results:

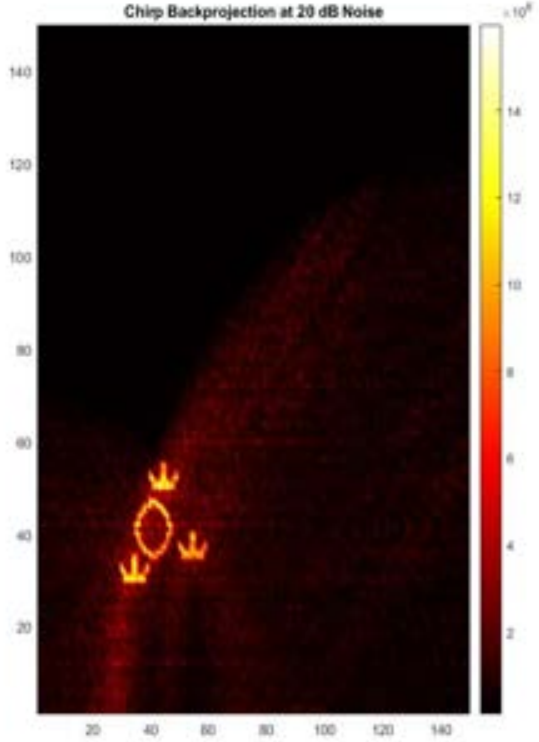
- Slightly higher sidelobes in Auto-Correlation when compared to LFM but excellent ambiguity function properties
- SAR performance directly comparable to performance of LFM chirp
- Slightly dimmer image but less “smearing”
- Additional benefit of immunity to repeat jamming due to regeneration of signal at each time step

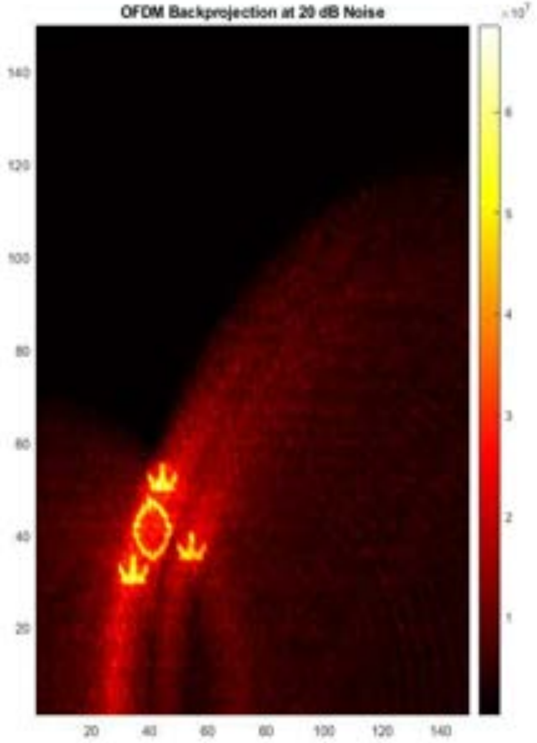


OFDM Signal Results:

- SAR performance directly comparable to performance of LFM chirp
- Increased security obtained through signal interleaving
  - Effect of greater number of interleaved signals tested (from 2 to 20 signals)
  - Intercepting receiver obtains roughly 2x greater BER compared to intended receiver







Conclusion:

- Dual functionality signals are feasible
  - Utilization of communications signals as radar signals can be an effective method of RADARCOMM
- Pseudo-random Chaotic signals and OFDM signals capable of adequate radar performance
  - Comparable to standard LFM chirp
- Chaotic and OFDM signals provide unique benefits as radar signals
  - Chaotic signal is highly resilient to repeat jamming
  - Unique method of randomized channel assignment provides OFDM signals with enhanced communications security