`Secure 5G for Tactical Environments

Proposal Submitted by InterDigital Communications, Inc.

For ONR BAA N00014-21-S-B0001

#	Item	Value
1	New or Resubmission	New
2	Type of Submission	Full Proposal - New for Contract from White Paper Submission (Requires ONR Tracking Number#)
3	ONR Tracking Number	
4	BAA/Special Notice/Funding Opportunity Number	BAA# N00014-21-S-B0001
7	Project Title	Secure 5G for Tactical Environments
8	Performer/Applicant Tracking Number (Optional)	
9	Performer/Applicant Name:	InterDigital Communications, Inc.
10	Performer/Applicant Address:	200 Bellevue Parkway, Suite 300 Wilmington, DE 19809 Tel: +1.302.281.3600 Fax: +1.302.281.3763
11	United States Performer/Applicant	Yes
12	Performer/Applicant CAGE Code	49MJ2
13	Performer/Applicant DUNS Number	057207953
14	Performer/Applicant DUNS Plus Four Segment	0000
15	Type of Business	Small Business
17	Principal Investigator Name	First Name: Sudhir Last Name: Pattar Email: Sudhir.Pattar@InterDigital.com Phone Number: +1 610-878-5616
18	Co-Principal Investigator Name	First Name: Philip Last Name: Pietraski Email: Philip.Pietraski@InterDigital.com Phone Number: +1 631-622-4192
20	Project Duration (by months)	36 months
21	Proposed Start Date	1st April, 2021
22	Short Project Description (500 characters)	Research and Demo 5G enhancements: Study and characterization of 5G performance in mmWave band for intra-ship communication and sensor data extraction using an aircraft.

23	Project Keywords (100 characters)	5G, low RF PSD, prototype, open source, ML, protocol exploits, mmWave, sub 6 GHz, 5G IAB
24	Will this effort contain Human, Animal, and/or Recombinant or Synthetic Nucleic Acid Molecules research?	No
25	If yes, which type?	

1 Technical Approach and Justification

1.1 Technical Approach

1.1.1 Technical Objectives

Following are the key (relevant) objectives of this project.

- ***Objective 4*:** Study and characterization of 5G performance in mmWave band for intra-ship communication.
  - ***Goal:*** Development of channel models for 5G intra-ship communication solution using tight power control and beamforming for use within compartments and roaming through halls in 60 GHz band.
  - ***Goal:*** Perform measurements to validate 60 GHz models.

1.1.1.1 Naval Use Cases

5G communications in mmWave band is a key enabling technology that offers extremely high data rate links (e.g., Gbps) due to the significant amounts of bandwidth available at mmWave frequencies. 5G NR FR2 band is defined in mmWave bands. While mmWave communications offers the promise of high bandwidth, following are some of the challenges of mmWave communications:

- **Limited range**: mmWave link budgets are dominated by significant RF propagation losses. Beamforming, beam steering and beam tracking with phased arrays is typically used in mobile mmWave systems to compensate for the increased propagation loss in higher frequency bands.
- **LOS communication**: Blockage from hand, body, walls, foliage, rain, etc. severely limits signal propagation. Advanced beamforming techniques combined with leveraging path diversity with massive MIMO techniques can be used to improve performance.
- **High Power Consumption**: mmWave RF processing is more power hungry with thermal challenges in small formfactor. These issues are exacerbated with the support for higher transmit powers desired for intra-ship communications.
- **Antenna Calibration and Housing**: To provide good mmWave antenna performance to support effective beamforming and beam nulling, careful calibration is required. Automated calibration may be required to maintain the performance. Additionally, the housing of the antennas must be carefully chosen to provide minimal absorption.

While RF propagation losses in mmWave bands are very high, this propagation loss can be used in advantage to reduce the RF footprint in adversarial spectral environments. Especially, At the millimeter wave frequency of 60 GHz, the absorption is very high, with 98 percent of the transmitted energy absorbed by atmospheric oxygen. While oxygen absorption at 60 GHz severely limits range, it also eliminates interference between same frequency terminals, benefits frequency reuse. Thus, mmWave communication coupled with beamforming and fast beam tracking can lower the power spectral density of RF energy. The RF signature can be further reduced by using power control algorithms that result in very low RF emissions beyond the intended recipient.

Detailed performance studies are needed to design the use of mmWave for inter-ship and intra-ship communications in corridors and rooms. The study needs to include:

- Modeling the channel for intra-ship RF environments using ray tracing and actual measurements.
- The design of the appropriate phased array antennas to support high gain beamforming.
- The comparative study of analog, all-digital and hybrid beamforming algorithms.
- The performance evaluation of 5G NR in the mmWave bands for the inter-ship and intra-ship channels

1.1.1.2 mmWave Performance Study

To design a 60 GHz mmWave system to provide intra-ship communications, the following key steps will be taken:

1) Propagation Channel Modeling: Understanding the channel behavior is a crucial for design of 5G mmWave communication. Unless channel models evaluated in 60 GHz band of ship corridors and rooms in ship are available as Government Furnished Information (GFI), then we will evaluate this using either of following methods:

- **Ray tracing model**: Using modeled or real-world environmental information, an accurate channel model can be created using popular ray tracking radio propagation tools such as Wireless InSite. The tool supports different types of materials and frequency bands and can accept 3D model data derived from laser scanning of the ship interior. Using simulation of ray propagation, power profile, delay profile, AoA, and AoD (Angle of Arrival/Departure) information can be generated for a given structure such as corridor or rooms with people and can be used in link level or system level simulations for variety of higher-level analysis including 5G link throughput, multiple access interference analysis and total network capacity measurements. InterDigital has done such type of extensive analysis for simulation-based contributions to 3GPP standards. Figure 1 illustrates an example of such an approach. Low-level element patterns are extracted from Antenna Design and Simulation (ADS) and fed into MATLAB Phased Array Toolbox for antenna pattern modeling. Phased array patterns are then used within link / system / network-level simulations for higher level analysis.

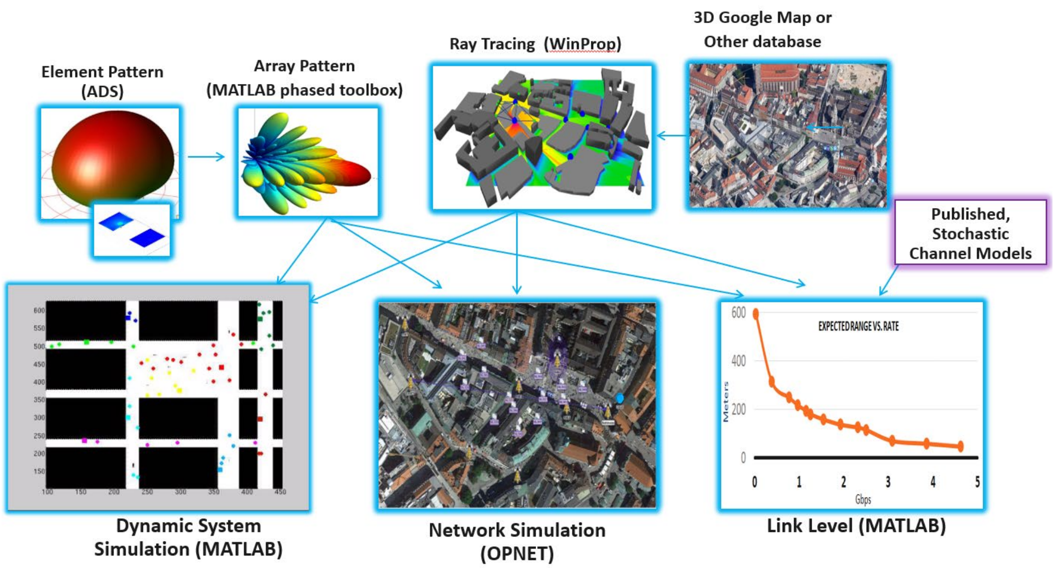

Figure 1 Performance analysis using ray tracing

- **Real World Measurements:** InterDigital has done extensive work in evaluating propagation characteristics in the 60 GHz band using real world measurement equipment. Figure 2 illustrates the block diagram of a historical 60 GHz measurement setup. The measurement setup planned for this project features automated antenna control to enable more accurate AoA/DoA estimation and wide band signal processing capable of estimating sub-nanosecond power delay profile (PDP). Based on the real-world measurements, a channel model was constructed for office buildings.

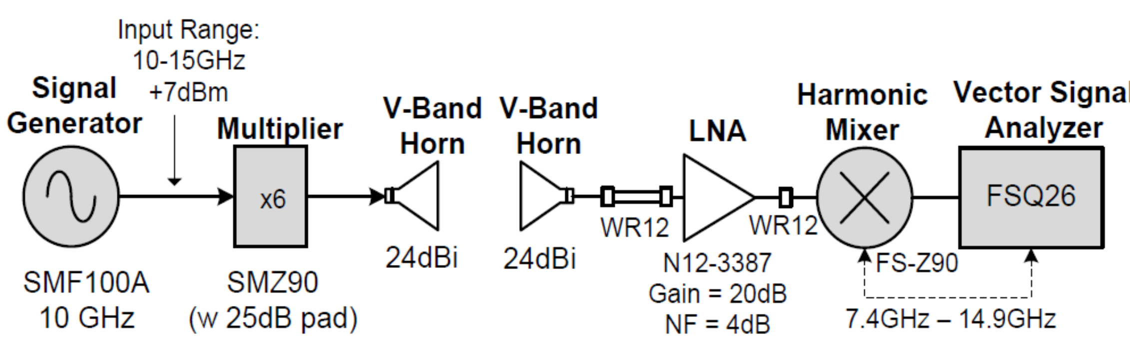

Figure 2 Block diagram of 60 GHz measurement setup

2) Performance evaluation of 5G:

Using the channel model, we can then use our 5G Link Level test bench we can evaluate the performance of the 5G system. Our 5G Link Level test bench is described in Section 1.3.4.1 and can be used to evaluate all the 5G Key Performance Indicators (KPIs) in the band of interest. Various types of beamforming algorithms and other techniques can be evaluated for their impact on the 5G link performance.

1.1.1.3 Brief Description of InterDigital 5G NR Platform

InterDigital has developed an FPGA based, NR Rel-15 mmWave prototype platform which will be leveraged for this project, The 28GHz platform consists of a Mast Head Unit (MHU's) outfitted with a 64-element antenna array, rated at +38dBm RMS EIRP, Quad analog phased array chips, 28 GHz up/down conversion from/to 5-6 GHz IF. The unit is housed in an IP67 compliant weatherproof enclosure. The baseband unit, Modem Processor Unit (MPU) is designed according to 3GPP Rel-15 PHY specifications and is implemented in a Xilinx MPSOC FPGA. The MPU contains two Xilinx Zu15EG SOM modules (2nd for future use), IF frontend, USB 2.0/3.0, SFP ports, Gigabit Ethernet interfaces and a SMA connection to the MHU. The MPU is configurable as either a 5G UE or gNodeB with the appropriate PHY, thin MAC/RLC functionality. The MHU supports QPSK, 16 QAM, 64 QAM and 256 QAM modulations.

Using this 5G NR platform along with open-source software for protocol stack, InterDigital has an end-to-end 5G NR solution that can be used for prototyping and experimentation of 5G enhancements or technologies based on top of 5G system.

1.1.1.4 About InterDigital

For four decades, InterDigital has been a pioneer in the wireless space, designing and developing a wide range of advanced technologies that are used in digital cellular and wireless products and networks, including 2G, 3G, 4G, 5G and IEEE 802-related products and networks. Today, InterDigital is a leader in 5G research and beyond, a thought leader in our industry and, over the course of the last two decades, the source of more than 5,000 contributions to key global standards. InterDigital has successfully completed multiple previous projects for the DoD. InterDigital has developed a mmWave 5G platform (demonstrated at MWC 2019) and is contributing to OpenAirInterface (OAI) to develop an open source 5G stack.