Realizing the full potential of data & learning within communications systems & wireless baseband

GTC 2019, San Jose

Dr. Tim O’Shea, CTO : tim@deepsig.io
3100 Clarendon Blvd, Suite 200 Arlington, VA 22201
www.deepsig.io
Brief DeepSig Overview / Background

Team:
Incredible team of AI, ML, SDR, DSP, & SW subject matter experts
Core team from GNU Radio, USRP, numerous other backgrounds
Growing rapidly

Seed Round:
$1.5M, March 2018
Scout Ventures (Lead), Blu Venture Investors
Actively seeking interested parties for further rapid scaling

Products:
OmniSIG and OmniPHY both shipping Software.
Numerous licensed software copies sold
Mature production C++11 code base for both

IP:
Several key patents on the technology allowed/issued (more pending)
Exclusive License of additional Patents from Virginia Tech

Innovation:
Top Recognized AI Wireless innovators
1100+ Citations of key early works
Software Radio Leadership (GNURadio)
Leaders IEEE / Industry Activities in ML Comms
The problem of Complexity in Wireless

• The Degrees of Freedom in wireless systems are expanding.
  • Antennas, channels, bands, codes, bandwidths, beams, modes, etc.,

• The types and effects of impairments continues to grow.
  • Rising noise floor, sources of interference, hardware imperfections, etc.,

• Spectrum environments and channel models are more difficult.
  • Number of devices, dense urban environments, unlicensed operation, etc.,

• The number of vectors for optimization is steadily increasing.
  • Dynamic radio behaviors, power usage (at both the UE and BTS), throughput, latency, coherence, etc.,
[Not] Coping with Wireless Complexity

- Complexity creates an extremely difficult design, optimization problem!
- The tools and methods for designing and optimizing wireless systems have not scaled with the problem complexity.
- Today systems are designed & optimized in modular / piecemeal fashion and then glued together.
  - This approach precludes end-to-end optimization
  - Often requires simplified world models within each module
  - Both result in sub-optimal solutions to today's communications systems

**The right way:**
- End-to-end optimization ... Using real world measurement instead of toy models
Challenges in Wireless Baseband

Make Wireless 5G+ and IoT Scale
  Increase Device Performance and Density
  Drastically reduce power consumption & device cost

Real Time Wireless Analytics
  Recognize device failures & wireless cyber attacks
  Learn from pattern of life, identify threats, anomalies
  Minimize cost and engineering time

Optimize Radio System Deployments
  Efficient planning of 5G, LTE-U & IoT
  Intelligent spectrum sharing strategies

Deployable Software Capabilities:
  Cloud managed infrastructure & optimization

---

Forget everything else!
My number one need is 5G power reduction!!

Nick Cordero, Verizon

If 5G is so important, why isn’t it secure?

Dr. Tom Wheeler, frmr chair FCC

Dynamic protection areas will spur spectrum sharing

Paige Atkins, NTIA
What DeepSig AI Software does for Wireless

Machine Learning Communications - new era of wireless that can optimize for many factors

- Improve Power Efficiency, Performance & Device Density in L1/PHY
  - Energy efficient operations learned from real data sets & hardware
- Reduce Wireless Device Cost – relax RF / linearity requirements
  
OmniPHY™ Baseband Technology

- Sense and exploit wireless information in real time
  - Plan/map cell performance, detect interference & malicious devices

OmniSIG™ Sensing Software
Tensor processing and machine learning ecosystem

- Key enablers for next generation baseband

OmniPHY™
OmniSIG™
Software Components

• TensorFlow
• PyTorch
• TensorRT

NVIDIA
Qualcomm Snapdragon
Xilinx

5G BTS
Mobile & IOT
Satellite & Backhaul
Defense ISR & Comms

Largest Impact
Early Opportunities
OmniSIG™ RF Sensing Software

- ~1000X faster & cheaper sensing
- Detect and map RF events and interference
- Rapid model updates and learning

"Y'all are so far ahead of your competition, it's kind of laughable."

Adam Thompson, NVIDIA

OmniSIG is providing about 700x speedup.

Navy SPAWAR
OmniPHY™ Baseband Technology

- Next leap of modem technology – end-to-end optimized PHY
- 10X+ Power Reduction, reduced cost, enhanced performance
- Better performance in Wireless WiFi, 4G/5G, IoT, NR-U Systems
- Fully Learned Waveforms: Satcom, Milcom, Mesh, 6G+

4G & 5G Massive MIMO & L1 enhancements
Learn Environment to Reduce Power/Cost

OmniPHY Secure SatCom & Drone Comm Link Learning

5G+/NR-U Performance Enhancements
Building Communications Systems with Deep Learning

- Autoencoder approach to communications systems
- Optimal communication schemes directly from data
- Scales from simple to complex channel models
Building Communications Systems with Deep Learning

- Performance converges rapidly to traditional ML bounds
  - Larger block sizes inherently learn error correction coding/gain
Building Communications Systems with Deep Learning

- Extending the approach to MIMO & Multi-User
- Major implications for massive densification
Building Communications Systems with Deep Learning

- Training for channels in the real world
  - Conditional-Comm-VGAN approach to stochastic channel response approximation
Building Communications Systems with Deep Learning

- Learning optimal communications for non-linear hardware effects
- Encoding for amplifier non-linearities!
- Enormous source of computational and power efficiency many systems

Constellation Learning

Amplifier AM/AM Response

Cellular Remote Radio Head / Amplifier
Building Communications Systems with Deep Learning

- Rapidly learn codes for a wide range of information rates
  - Built in error correction
  - Low complexity
  - A Number of modes which can be used in OmniPHY shown here
- Can also cascade traditional error correction
Building Communications Systems with Deep Learning

- Real world deployments of OmniPHY
  - Optimized satellite communications link /w NASA
    - Adaptation to reduce power, improve performance
    - Achieved lower BER than traditional system
  - Secure resilient drone communications & sensing (Tx2)
    - Adaptation avoid interference & attack
    - Live video streaming & telemetry
    - AES-256-GCM (FIPS 140-2 approved link crypto)

- Software shipping / available
Building Communications Systems with Deep Learning

- Speed benchmarking on OmniPHY decoder
  - Relatively compact networks --
    - Partial optimization –
    - Optimized C++ implementation
    - Still float32 inference on desktop GPU
  - GTX 1080
    - > 140 Mbps throughput
    - 57 ns/bit inference speed
    - ~109μS per inference round trip latency
  - Bottlenecks typically on the CPU …

- Numerous additional performance improvements remain
  - Tensor core / DLA performance additional gains
  - Larger sensing networks (~100+ layers deep)
    - < 5ms per inference latency
    - 200+ full spectrum characterizations per second
Building Communications Systems with Deep Learning

• Tensor processing and machine learning go hand-in-hand
  • Energy efficient partial 4G & 5G basebands using tensor ops
  • Easily insert ML enhancements throughout the physical layer

• Key enabler for DeepSig cellular enhancements
  • Drastically reduce power consumption and cost in BTS
  • Widely applicable for deployment of numerous wireless systems
  • Enable rapid development and iteration of algorithms and performance in real world environments
Building Communications Systems with Deep Learning

- Enhancing 5G Systems with Machine Learning
  - Same approaches can be used to significantly reduce the power consumption in commercial standards
  - Adapt performance on real hardware & adapt algorithms in end-to-end optimization manner

50% Reduction in EVM under Imperfect CSI! (4x4 MIMO case) – Resilient to PA compression!
  - Single pass deep learning approach – no iteration required (e.g. convex solver)
Object detection has shown incredible results in computer vision.

- Detecting and classifying objects in a real 3D scene.
- Critical in self driving cars, surveillance, and numerous applications.
- Networks like YOLOv3 have made this very efficient.
Building RF Sensing Systems with Deep Learning

- Object detection in the RF spectrum is a critical enabler to awareness
  - Malicious activity detection
  - Device interference detection
  - Dynamic spectrum access and ISM band coordination
  - Surveillance and monitoring
- Has never really been feasible are practical before at wide bandwidths across many signal types
Building RF Sensing Systems with Deep Learning

- OmniSIG is the state of the art in applied wideband RF object detection
  - Making sense out of the RF firehose
  - Gbits of raw RF samples → kbits of SIGMF JSON describing all activity in the spectrum
  - Now deployed with a range of customers and signal sets – continuing to improve performance daily
Building RF Sensing Systems with Deep Learning

- Accelerating inference using TensorRT and optimized concurrent C++ deployment
- Managing concurrency throughout the application is critical
- Pipeline and data parallelism
- Performance scaling across CPU, to GPU, to TensorRT+GPU
- Still more optimization to come!
Building RF Sensing Systems with Deep Learning

- Accelerating and deploying inference at the edge on Xavier AGX
- Leveraging TensorRT to accelerate inference
- Closing gap between server and edge class devices
- Real time comms and sensing from low SWaP UAS platforms
Building RF Sensing Systems with Deep Learning

- Real time detection makes new applications possible
- Streaming wideband RF signal detection, mapping, L1 statistics monitoring, and analysis
  - Rich performance measurement and drive analysis tools
  - Rapid propagation modeling and analysis tools for cellular planning and prediction
- Streaming anomaly detection and band change detection
- Streaming interference detection
- Physical perimeter security
- Cell deployment planning

OmniSig Mobile Cellular Performance Analytics
Building RF Sensing Systems with Deep Learning

- **OmniSIG SDK** – Learning on your data
- SDK tools to rapidly annotate and curate RF datasets
  - Make massive unlabeled RF data manageable
- Rapidly update OmniSIG on new datasets
- Makes DL based sensing widely accessible to others for many apps
- Convenient cloud and web based deployment
Growing interest in this area throughout research in industry and academia

DeepSig is actively leading professional society initiatives

IEEE Emerging Technology Initiative :: Machine Learning for Communications
  - Specifically focused on applications in the Physical Layer
  - Led by Jakob Hoydis, Nokia Bell Labs; Tim O’Shea, DeepSig; Elisabeth de Carvalho, Aalborg U.
  - [http://mlc.committees.comsoc.org](http://mlc.committees.comsoc.org)

Initial activities include:
  - MLC: Tutorials, Special Issues, Possible Summer School
  - MLC: Datasets & Competitions
    - Several current data competitions, culminating at IEEE Comm. Theory Workshop
  - MLC: Industry relationships, blog posts, mail list
  - MLC: Research paper library, references, curation
Thanks

DeepSig Inc.
3100 N. Clarendon Blvd.
Suite #200
Arlington, VA, 22201

info@deepsig.io
(703) 340-1451

https://deepsig.io