



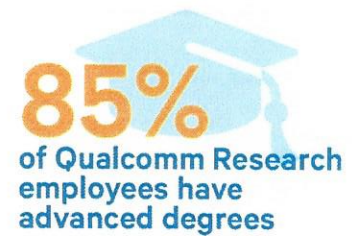
Qualcomm Research Quarterly Overview

Scott Nyberg
Sr. Marketing Manager
Qualcomm Research
Qualcomm Technologies, Inc.
July 2017

Qualcomm Research

Qualcomm Research is a world-class R&D organization comprised of an international team of forward-thinking researchers collaborating on a wide variety of exciting and technically challenging projects. We push the envelope of what's possible in semiconductor and mobile technologies, passionately advancing their research, prototyping, and standardization across many industry verticals.

**Engineering our products
across**



Qualcomm Research Global Locations



San Diego, CA
Research HQ & Invention Incubator



Bridgewater, NJ
Multi-User Mobile Access Technology



Amsterdam
Deep Learning and Computer Vision



India
Wireless, Multimedia, Computer Vision



Silicon Valley, CA
Low-power Sensors



Raleigh, NC
Processors & Circuit Design



Austria
Computer Vision



Korea
Machine Learning & Signal Processing



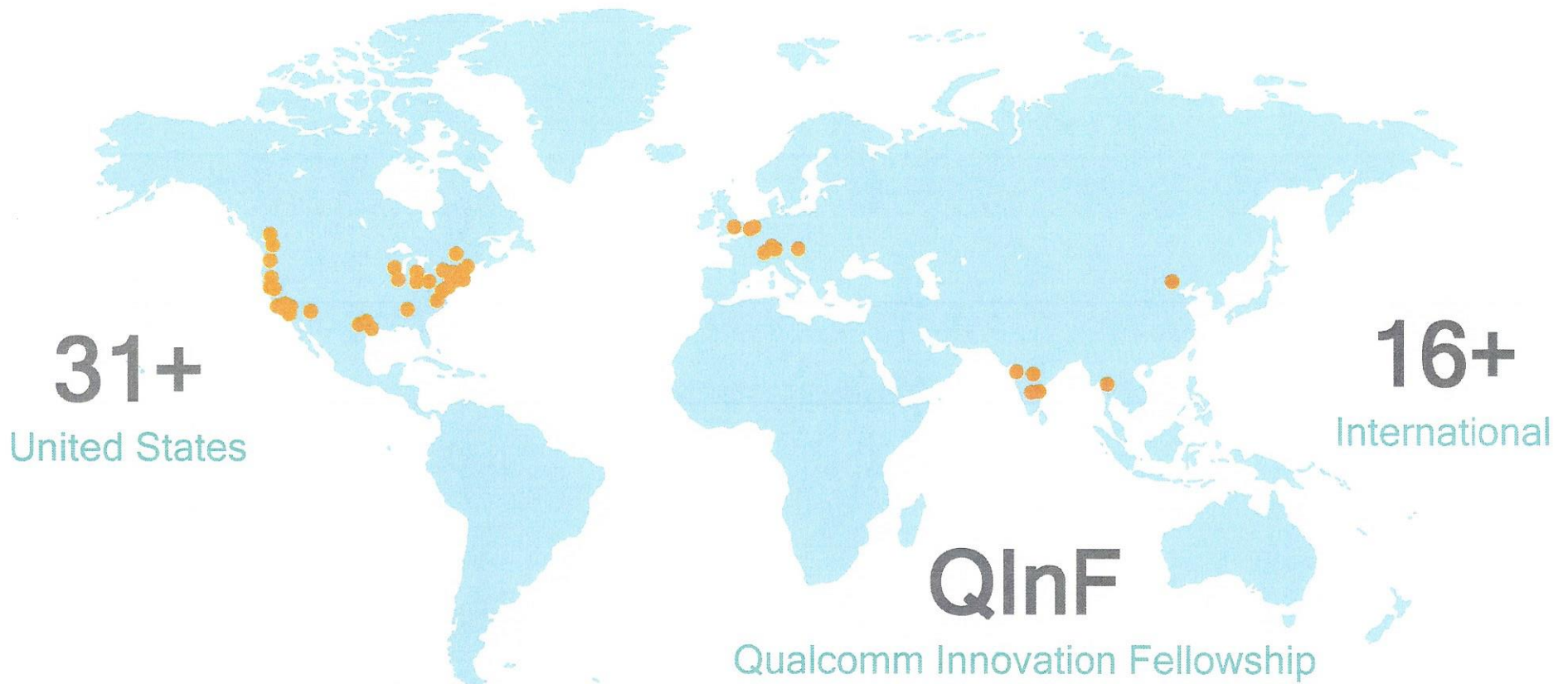
Philadelphia, PA
Robotics & Drone Technologies



China
Air Interface Technologies
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Qualcomm Research University Relations

Collaboration with Universities Worldwide



Core Research Areas

Focusing on future technologies that are 3-10 years from commercialization



5G



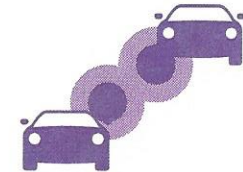
Shared Spectrum Technologies



Wi-Fi



Industrial IOT



Cellular - V2X



Deep Learning



Autonomous Driving



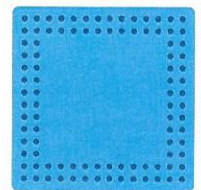
Autonomous Robotics



Virtual Reality



Low-power Processors & Sensors



ASIC & Hardware R&D

Getting the Most out of Every Bit of Spectrum Available

Addressing Tomorrow's Massive Connectivity Challenges



Low bands below 1 GHz: longer range for e.g. mobile broadband and massive IoT
e.g. 600 MHz, 700 MHz, 850/900 MHz

Mid bands 1 GHz to 6 GHz: wider bandwidths for e.g. eMBB and mission-critical
e.g. 3.4-3.8 GHz, 3.8-4.2 GHz, 4.4-4.9 GHz

High bands above 24 GHz (mmWave): extreme bandwidths
e.g. 24.25-27.5 GHz, 27.5-29.5, 37-40, 64-71 GHz

Licensed Spectrum

Exclusive use

Shared Spectrum

New shared spectrum paradigms

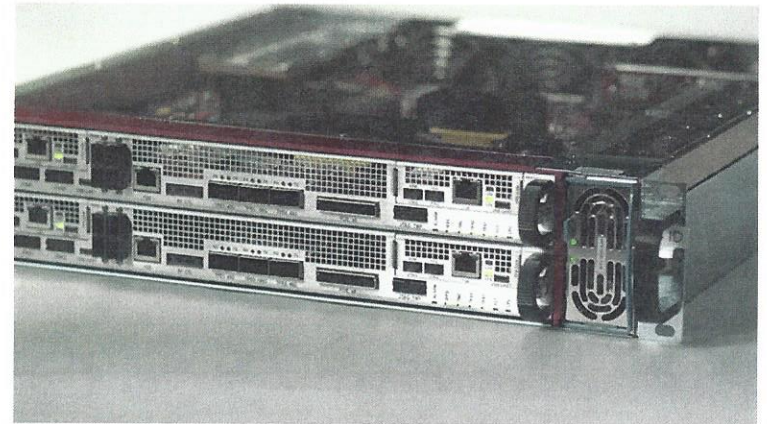
Unlicensed Spectrum

Shared use

5G NR sub-6 GHz

A Flexible Air Interface Framework for Efficient Multiplexing of Diverse Service Types

- 5G sub-6 system design
 - Advanced radio interface techniques including:
 - Scalable OFDM numerology
 - Self-contained integrated sub-frame
 - Flexible LDPC coding
 - Multi-user Massive MIMO
 - Upper layer design includes uplink-based mobility, enhanced security, & network/service slicing
- 5G sub-6 prototype/demo development
 - Based on the evolving 3GPP 5G NR specification
 - Supports scalable bandwidth in units of 100 MHz
 - Delivers wide area coverage at ~ 4 GHz
 - Achieves multi-Gbps data rate and sub-2ms latency

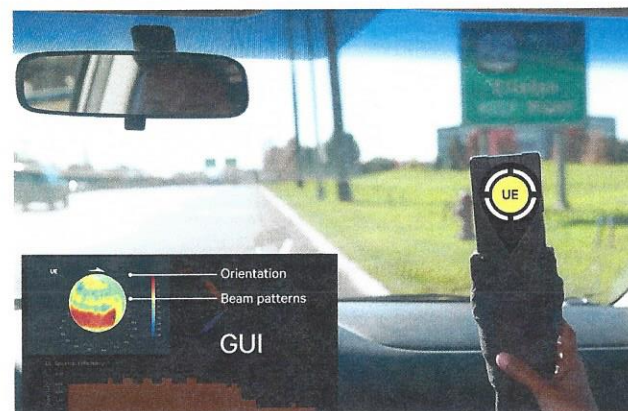


Demonstrated at MWC 2017

5G NR mmWave

Overcoming Robustness Challenge Due to High Path Loss & Susceptibility to Blockage

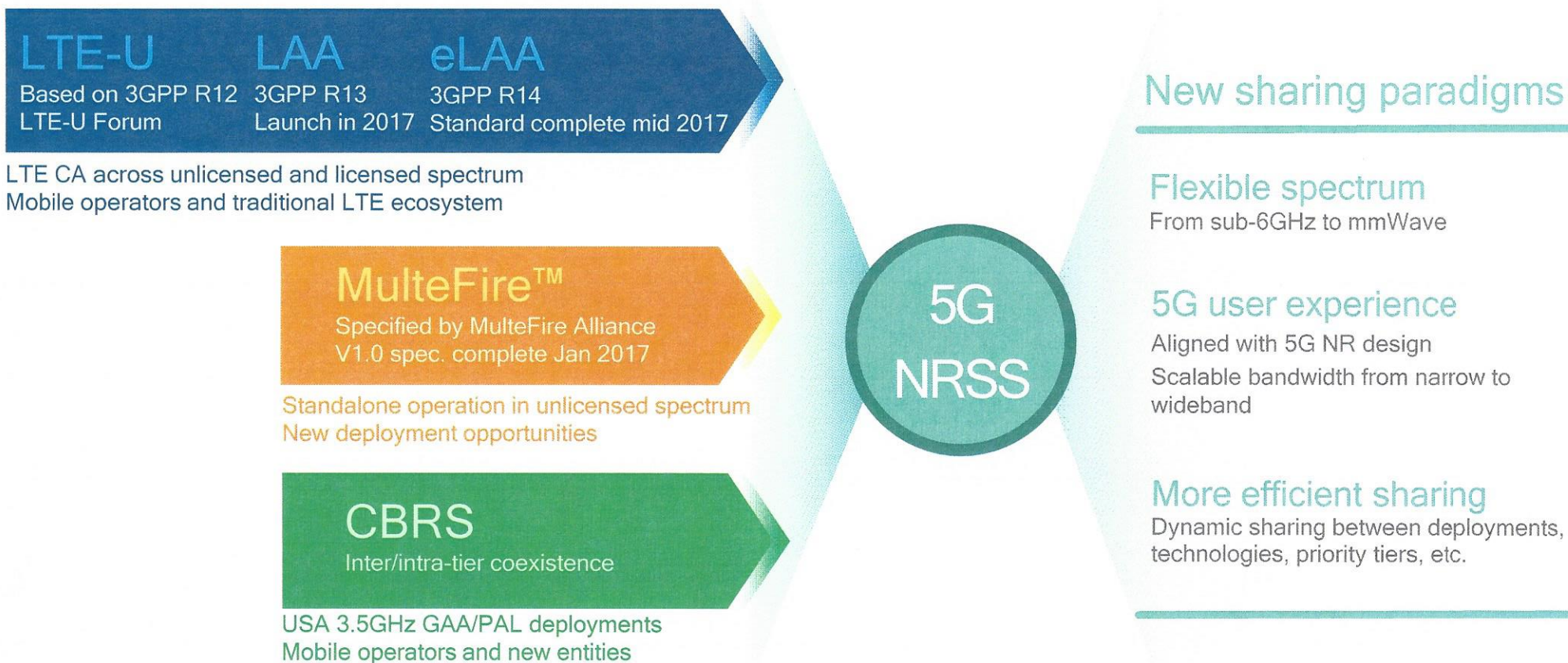
- 5G mmWave system design
 - Developed advanced radio interface techniques including:
 - Beamforming
 - Intelligent beam tracking
 - Dynamic point selection
 - Delivers improved range, enhanced mobility, and sustained broadband communications even in NLOS environments
- 5G mmWave prototype/demo development:
 - Operates in the 28 GHz band
 - Supports NLOS and mobility scenarios
 - Utilizes large antenna arrays to support beamforming with the ability to dynamically discover and switch to the dominant beam path within and across base stations



Demonstrated at MWC 2017

Cellular Technologies for Unlicensed/Shared Spectrum

Creating a Better User Experience by Efficiently Using Shared/Unlicensed Spectrum



MulteFire™ Technology

Enabling Standalone LTE Operation in Unlicensed/Shared Spectrum

- System design and performance evaluation
 - Aligned with 3GPP LAA/eLAA design
 - Coexistence with Wi-Fi via Listen-Before-Talk (LBT)
 - Enhanced discovery & control signals
 - Robust access and mobility procedures in unlicensed band
- Prototypes/testbeds supporting early demos and trials
- Simulation and field trials show MulteFire performance advantages
 - 2~3x capacity gains over Wi-Fi in dense deployment
 - ~2x outdoor coverage compared to Wi-Fi
- Standardization
 - A founder and key contributor to MulteFire Alliance
 - V1.0 spec is completed targeting mobile broadband and high performance IoT in 5GHz and CBRS
 - V1.1 work is on-going that will address new IOT use cases
 - Supporting lower bandwidth, wide area IoT using 2.4GHz and sub-GHz unlicensed band aligned with eMTC & NB-IoT

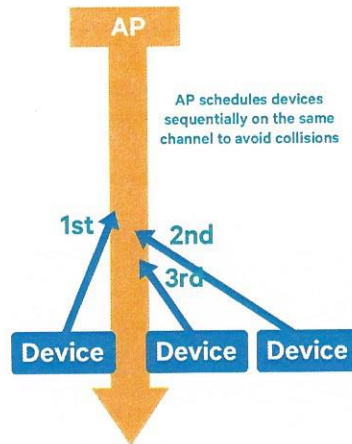


MulteFire™ and 5G NR SS Testbed/Demo

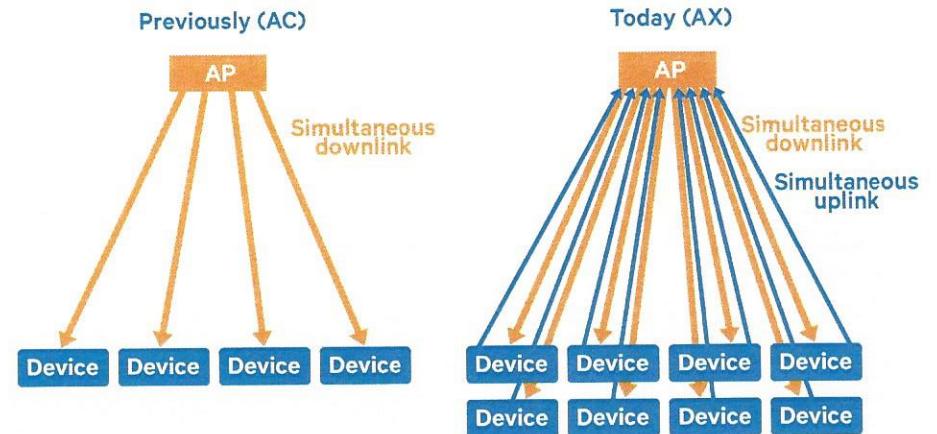
- First MulteFire multi-node OTA demo (Oct 2016)
 - Testbed at our San Diego campus
 - 4 MulteFire eNBs operating in 5GHz band
- MWC 2017 live OTA demo
 - Indoor and outdoors with handovers
 - Shared spectrum fairly with Wi-Fi, while offering higher performance, e.g., seamless mobility
 - Bringing the benefits of LTE to a larger ecosystem
 - Lab demo previewed 5G spectrum sharing benefits
- Testbed/prototype expanding to support 5G NRSS

Wi-Fi 802.11ax

Overcoming Interference Issues and Increasing Capacity in Dense Environments



Introduced UL Scheduling so APs can Schedule Devices Sequentially, thus Avoiding Collisions

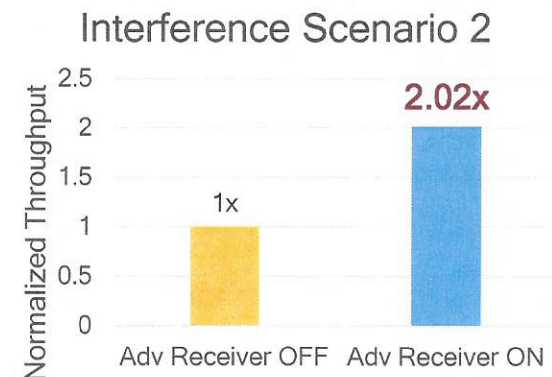
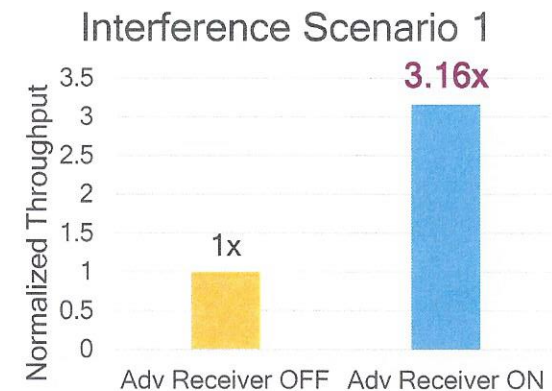


MU-MIMO Allows Simultaneous Transmissions in the Uplink and Downlink for Multiple Users

Wi-Fi Advanced Receiver

Lessening Interference Introduced by Devices Competing for the Same Channel

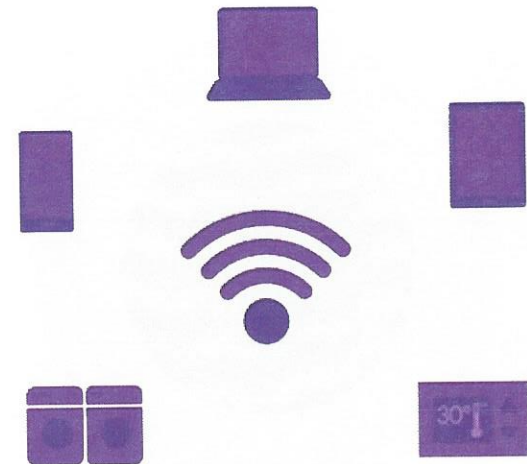
- Key issue: In dense Wi-Fi deployments, hidden nodes and collisions create interference and slash network throughput
- Receiver mitigates interference and improves device performance, enabling high throughputs
- MWC 2017 demo
 - Receiver suppressed the interference and delivers 2x - 3x throughput improvement



Wi-Fi SON

Managing Signal De-confliction to Ensure Network Performance Optimization

- Eases the deployment of Wi-Fi networks in large/dense environments
- First product that integrated the initial Wi-Fi SON features is in the market today with more to come
- New additions to our Wi-Fi SON sensor suite include:
Interference Avoidance Steering and Single AP
Smooth Channel Switching



Industrial IoT

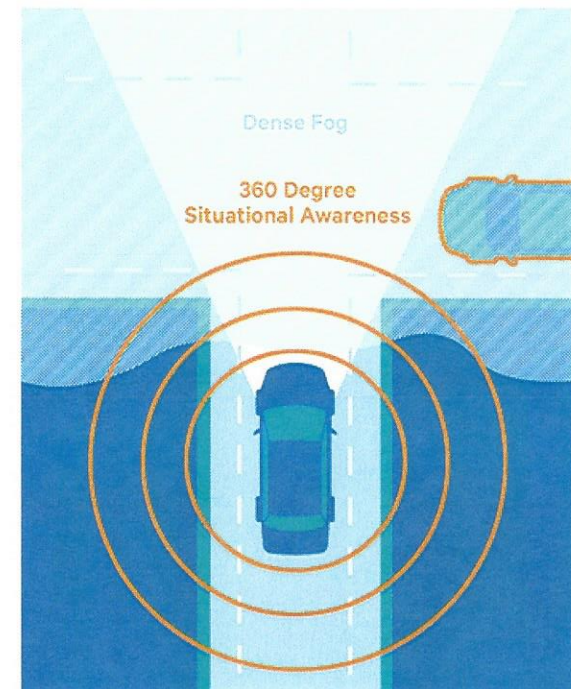
Enabling Private LTE Network Connectivity within Localized Areas

- Private IoT combines LTE-grade performance with Wi-Fi-like simplicity, leveraging 4G LTE air interfaces that dwell in 3.5 GHz and 5 GHz bands
- Security credentials for IoT devices can be embedded (non-SIM authentication)
- Factory-based LTE Private Network demonstrated at MWC 2017

C-V2X

More Reliability and Better NLOS Performance for Enhanced Safety Use Cases

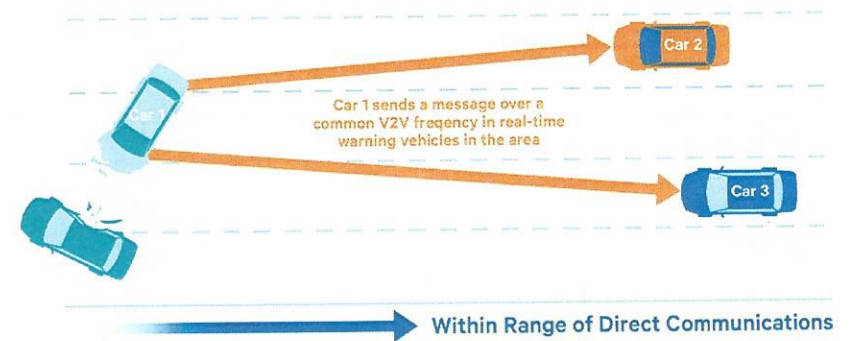
- C-V2X is a modern V2X alternative and a complement to 802.11p
- Supports rapidly evolving safety requirements and use cases
- Can be integrated with the upper layers of SAE and ETSI-ITS
- Better range (approx. 2x) than 802.11p
- Provides 360-degree BLOS awareness



C-V2X

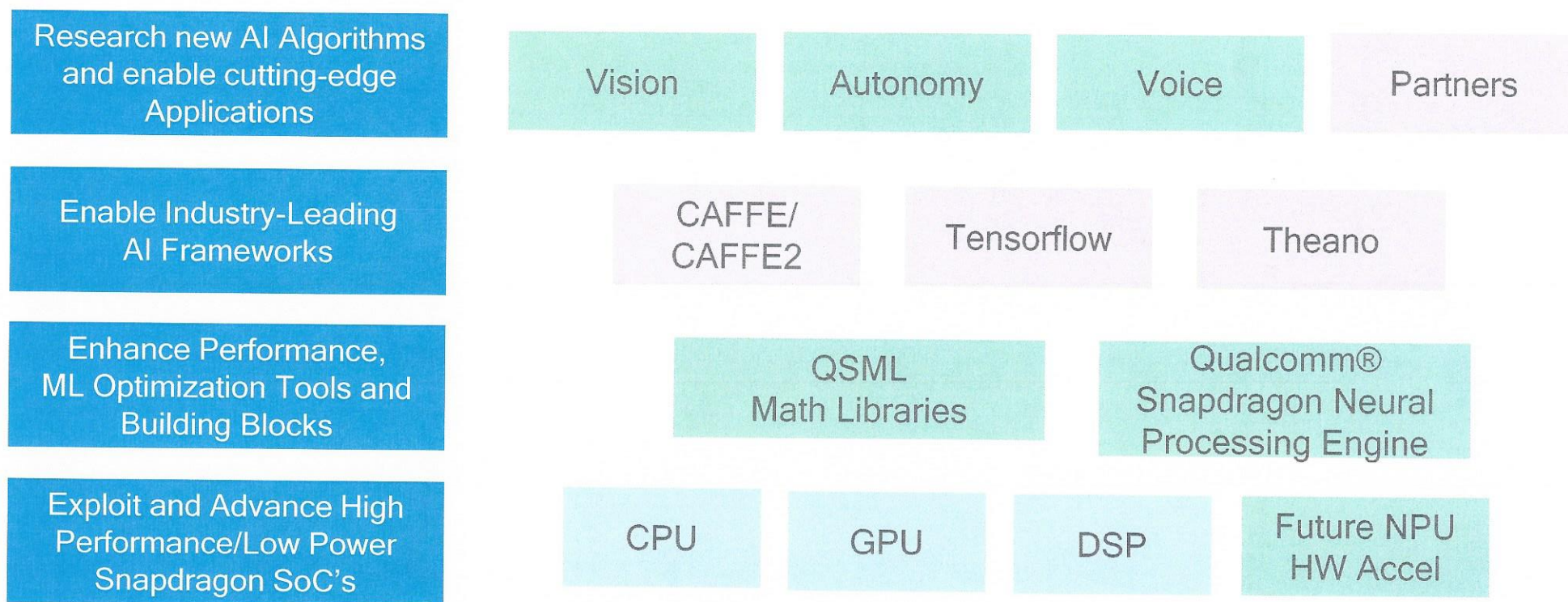
Ensuring Communications within In-Coverage and Out-of-Coverage Areas

- Direct communications mode
 - Enables the exchange of real-time data between vehicles traveling at high speed at long distances
- Network communications mode
 - Vehicles communicate with C-V2X servers



Deep Learning: Enabling AI “Everywhere”

Overcoming Challenges of Performance and Power-Constrained Embedded Devices



Legend

- CR&D Efforts
- External
- Hardware Chipset

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Deep Learning: Supporting AI Vision on Edge Devices

Optimizing Complex Deep Learning Algorithms for Mobile

- SSD Neural Network performs simultaneous object detection, localization/classification of objects
- A complex workload previously not feasible on Mobile devices
- Ran on tablet with a Qualcomm® Snapdragon™ processor in live view analyzing street scenes in Amsterdam
- Classifying cars, bicycles, people, other objects of interest in a visual scene
- Illustrates the performance of Snapdragon NPE

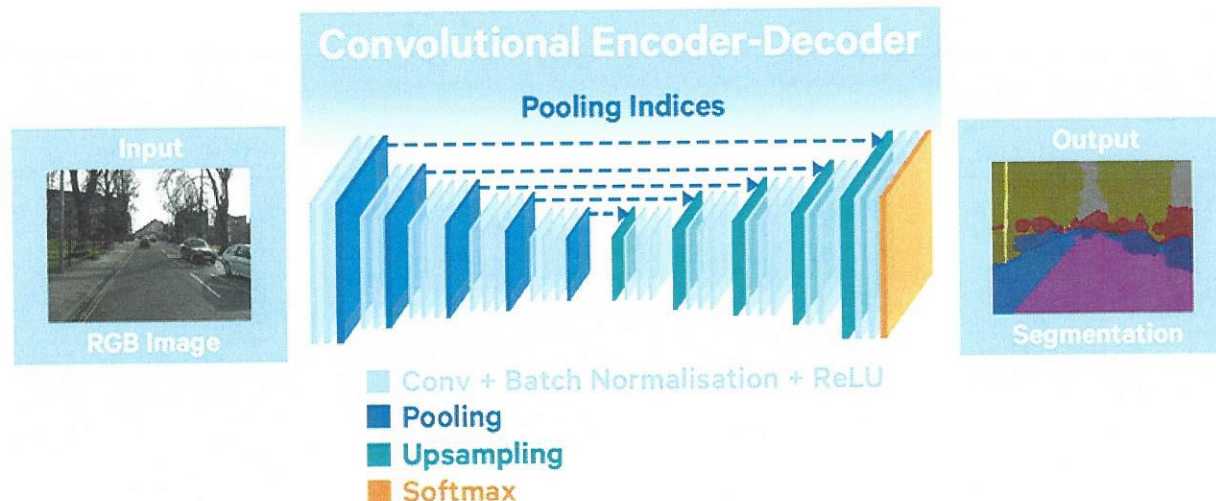


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Deep Learning: Enabling Autonomy with AI on Qualcomm® Snapdragon™ NPE

Leveraging Semantic Segmentation Network for Object Classification

- A pixel level map is built by labelling every pixel in an image in order to categorize objects
- Colored pixels of specific regions indicate the different classes of objects in a scene
- Neural Network hyperparameter Optimization for Automotive and Autonomous drone use cases



60+X
Performance
Improvement
over baseline
performance by
using
Snapdragon
NPE

Autonomous Driving

Achieving Highly Accurate Positioning with VIO + GPS

- Generates continuous localization resulting in a 6-DOF pose
- Delivers precise sensor synchronization
- Enables sub-meter positioning globally and cm-level positioning on the map
- Demonstrated at CES 2017



Autonomous Driving

Enabling Massive Edge Analytics on a SoC

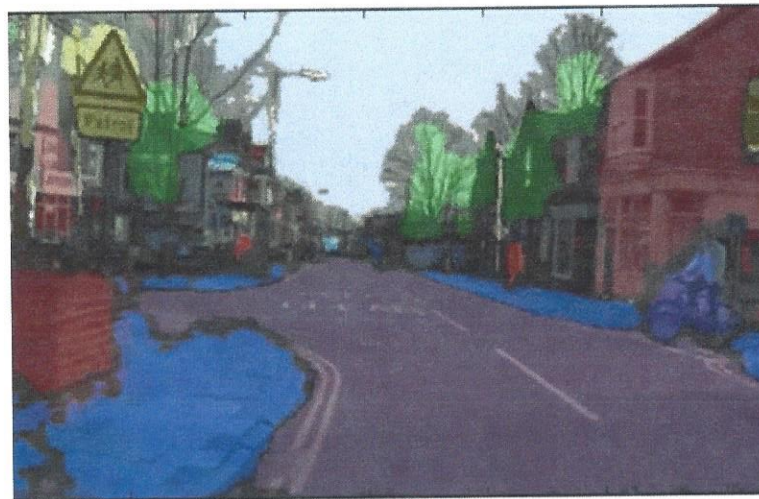
- Performs low power, on-device machine learning
- Runs on a smartphone-class SoC
- Vertex SSD detects traffic sign vertices with pixel level accuracy
 - Demonstrated at CES 2017



Autonomous Driving

Updating Accurate Localization Data for HD Maps

- Vehicles collect and send metadata to the cloud at just tens of kB per km instead of raw sensor data streams at GB of data /sec
- Edge analytics and our cloud processing engine creates the map
- Allows real-time, frequent updates to HD maps through crowdsourcing for autonomous driving applications
- Demonstrated at CES 2017

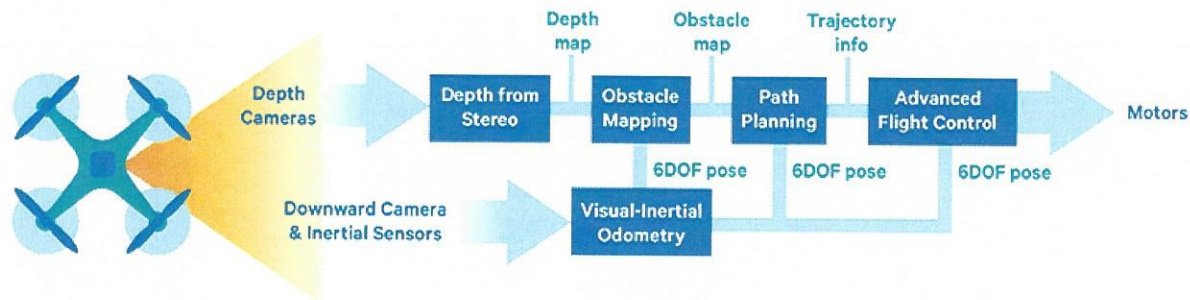


Unknown
Bicycle
Pedestrian
Car
Fence
SignSymbol
Tree
Sidewalk
Road
Pole
Building
Sky

Autonomous Robotics

Avoiding Obstacles via Autonomous Navigation & Path Planning

- **Depth from Stereo** determines the drone's proximity to the object and creates a 2-D depth map
- **Visual-Inertial Odometry** generates a 6-DOF pose in real-time with cm-level accuracy
 - Leveraged during obstacle mapping to accurately stitch the maps together for path planning
- **Advanced Flight Controls / Electronic Speed Control** monitors and regulates motor speeds



Autonomous Robotics

Enabling Localization, Vision-Based Synchronization, and Obstacle Avoidance



Demonstrated at CES 2017

Autonomous Robotics

Enabling Drone Cellular Connectivity for Safer, Beyond Line-of-Sight Drone Operations

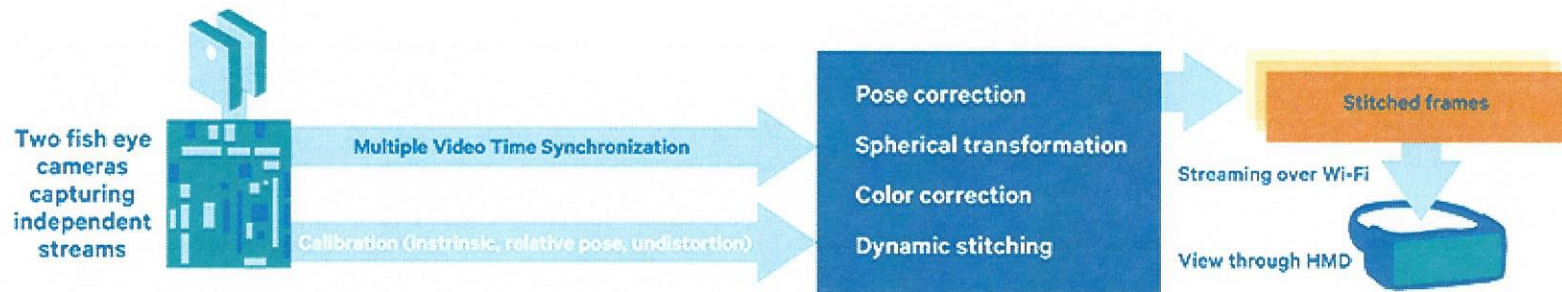
- Our testing found that today's LTE networks can serve drones at low altitudes
 - Drones at low altitudes up to 400ft experienced good coverage and seamless handover
- Conducting additional testing and simulations to optimize LTE for better interference mitigation and drone connectivity performance
- We're leading 5G design and 3GPP standardization to enable widescale deployments of mission-critical drone use cases



Virtual Reality

Generating High Quality On-Device 360-degree VR Content

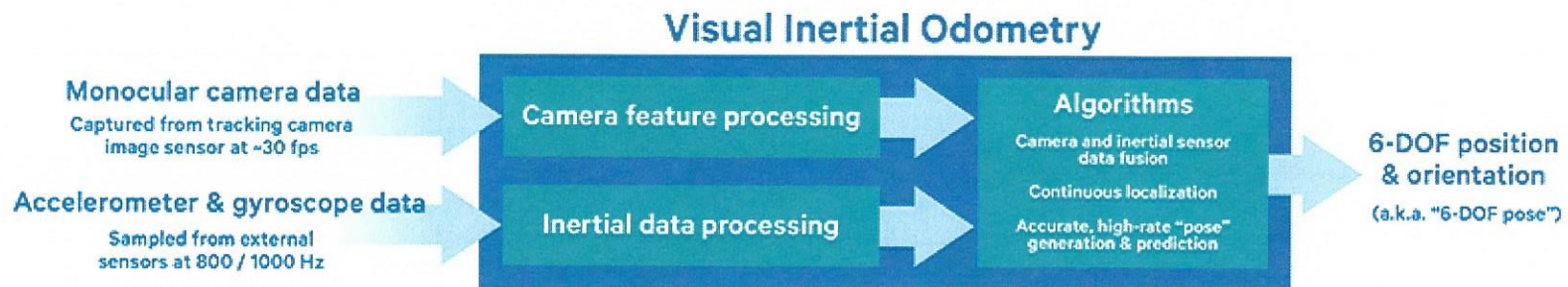
- Power-efficient heterogeneous computing stitching solution optimized to deliver 4K/30 FPS
- Sensors capture 360-degree images in smooth synchronization
- We have developed real-time image processing of 2 camera sensors in a single SoC solution
- CPUs & GPUs enable real-time analysis and correction of color mismatches between cameras as well as ghosting artifacts while stitching contents from multiple cameras



Virtual Reality

Delivering Highly Accurate Head Motion Tracking

- Enables highly-accurate, power-efficient, low latency 6-DOF motion tracking of head movements on our mobile platform
- Through VIO, camera frames at 30 FPS are fused with IMU data between 800 - 1000 Hz resulting in continuous localization, and accurate, high-rate 6-DOF pose generation and prediction



Virtual Reality

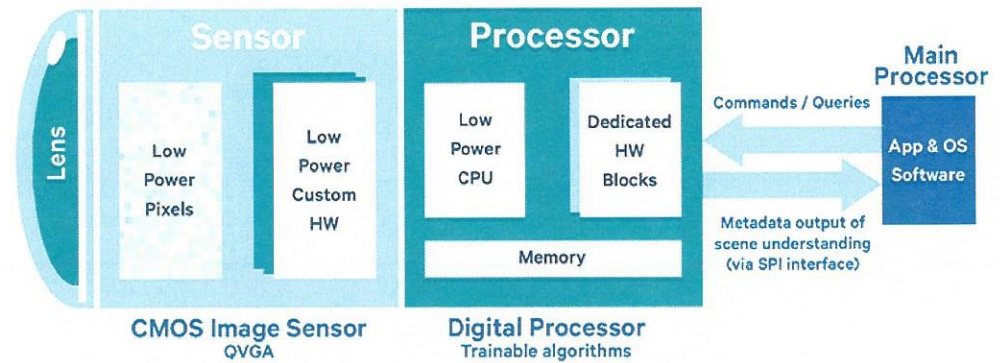
Cutting-Edge Demo at CES 2017



Always-On Computer Vision Module

Providing Smartphones & IoT Devices with Affordable, Always-On CV Awareness


- <2mW average end-to-end power
 - Orders of magnitude lower power efficiency than traditional CV solutions
 - Below the threshold of “always-on”
- Standalone sensor, independent of main processor. Output is metadata via SPI
- Significantly more intelligent than “always-on” alternatives (e.g. PIR)
- Performs object detection, feature recognition, change/motion detection



*3.6 x 4.0 x 2.5mm form factor
for entire module*


Always-On Computer Vision Module

Enhancing User Experience and Convenience for Devices and Appliances




Smartphone

- Face-based auto-wake & auto-sleep
- Always-on trigger for other use cases
 - e.g., Always-on trigger for iris authentication (removes multiple steps and user initiation)




Smart Watch

- Face-based auto-wake & auto-sleep
- Always-on gestures*




Tablets

- Simple gaze tracking for advertising attribution*
- Better landscape/portrait screen orientation




Virtual Reality

- Lower power gaze tracking (foveated rendering)*
- Lower power VIO for 6dof*




'Intelligent' Occupancy Trigger*

- Intelligent replacement for PIR/motion triggers:
 - Distinguish humans from other objects
 - Add data layer to trigger: How many? Where?
 - Trigger on particular events or objects



'Intelligent' Interactivity Trigger*

- Face detection as a trigger for interactivity
- Smart appliance can react when a user approaches to engage it



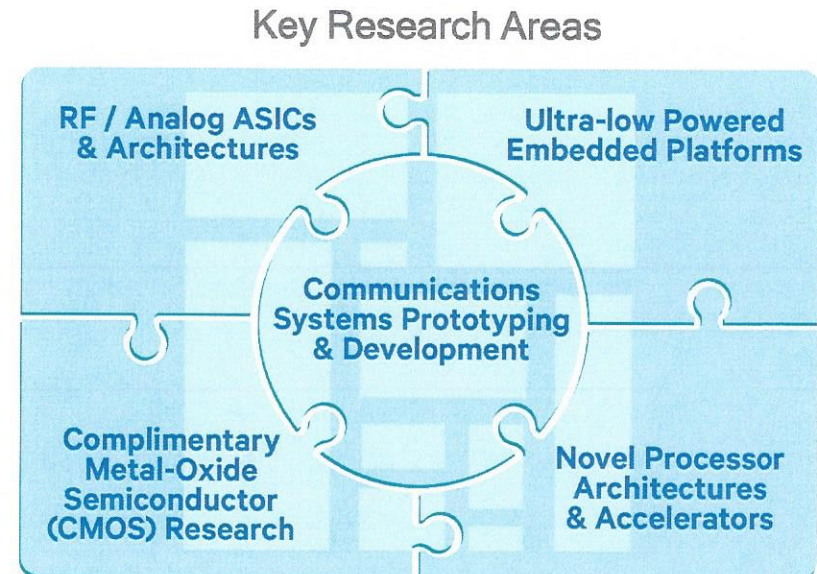
Standalone Intelligent Data Sensor*

- Heat maps of how a space is occupied
- Privacy advantages - data only, no images captured

ASIC & Hardware R&D

Supporting the Development of Communication Systems and Embedded IoE

- 5G (antennas, RF ICs, power amplifiers, interfaces, packaging)
- Processors (next-gen CPUs, programmable deep learning accelerators)
- Ultra-low power platforms (communications, memory systems including non-volatile memories, power management units, and wireless charging)
- CMOS (3D IC, thermal-aware designs, circuits)
- Antenna design



Thank you



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