COMMERCIAL 5G RADIOS AS A BUILDING BLOCK FOR TACTICAL WIRELESS COMMUNICATIONS

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VERTICALS ENABLED BY 5G

ENHANCED MOBILE BROADBAND (EMBB)

- High peak throughput
- High spectral efficiency
- High capacity
- Mobility

MASSIVE MACHINE-TYPE COMMUNICATION (MMTC)

- Network and device energy efficiency
- Massive number of connections
- Very large coverage

ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC)

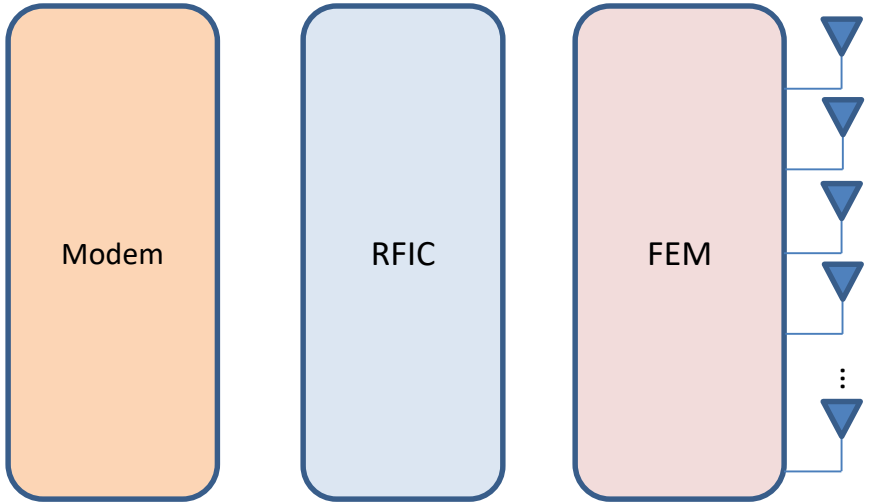
- Ultra-high reliability
- Ultra-low latency

Sabine Roessel – 5G for Cellular IoT – April 27th, 2017

From: Dark As Dark Can, The Untold Keynote – May 2015, Sabine Roessel

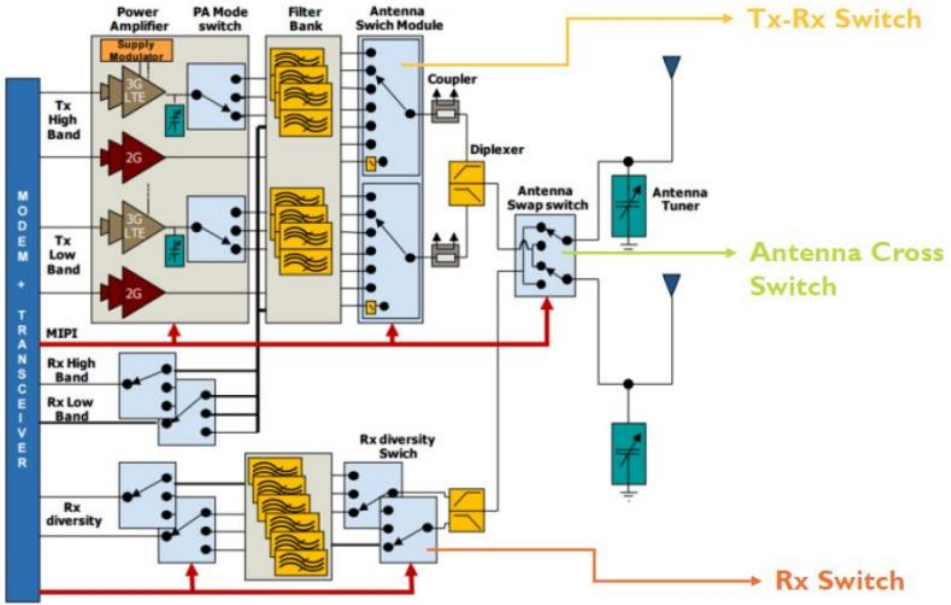
ANATOMY OF A 5G RADIO

1. Modem
   - Commercial or ASIC/FPGA proprietary
2. RFIC
   - Flexible, configurable
3. FEM (Front-end Module)
   - Application specific



FRONT-END MODULE

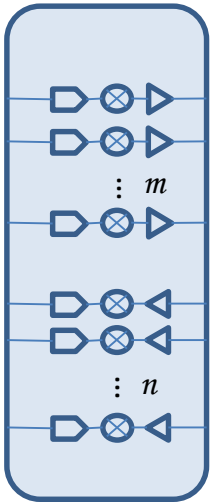
- Complex and applications specific modules containing PA, LNA, filters and switches
- Constrained by protocol used and local regulations



Source: Yole, 2017 5G's impact on RF front-end industry

RFIC

- Flexible, configurable
- Protocol and waveform agnostic
- Massive MIMO
- Broadband, multiband
  - ~ 600MHz-6GHz
- Multi Gbps throughput
- Full-duplex operation possible utilizing Self-Interference Cancellation techniques



5G RFIC

MODEM

- Fully compliant 3GPP 5G NR
  - SA and NSA support
  - sub6GHz and mmWave band support
  - Scalable numerology (sub-carrier spacing, CP, slot length)
  - Modular slot/frame structure

	LTE	New Radio
Maximum Bandwidth (per CC)	20 MHz	50 MHz (@ 15 kHz), 100 MHz (@ 30 kHz), 200 MHz (@ 60 kHz), 400 MHz (@ 120 kHz)
Maximum CCs	5 (currently)	16 (allowed BW and CCs combinations TBD)
Subcarrier Spacing	15 kHz	2^n • 15 kHz TDM and FDM multiplexing
Waveform	CP-OFDM for DL; SC-FDMA for UL	CP-OFDM for DL; CP-OFDM and DFT-s-OFDM for UL
Maximum Number of Subcarriers	1200	3300
Subframe Length	1 ms (moving to 0.5 ms)	1 ms
Latency (Air Interface)	1 ms (moving to 0.5 ms)	1 ms
Slot Length	7 symbols in 500 µs	14 symbols (duration depends on subcarrier spacing) 2, 4 and 7 symbols for mini-slots
Channel Coding	Turbo Code (data); TBCC (control)	Polar Codes (control); LDPC (data)
Initial Access	No beamforming	Beamforming
MIMO	8x8	8x8
Reference Signals	UE Specific DMRS and Cell Specific RS	Front-loaded DMRS (UE-specific)
Duplexing	FDD, Static TDD	FDD, Static TDD, Dynamic TDD

BEAMFORMING FOR MMWAVE

- Complex and fast beam management will be required for mmWave applications

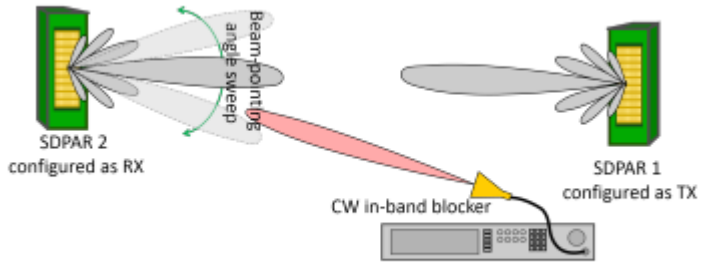


Fig. 6. Setup of an example experiment using two SDPARs and an interferer

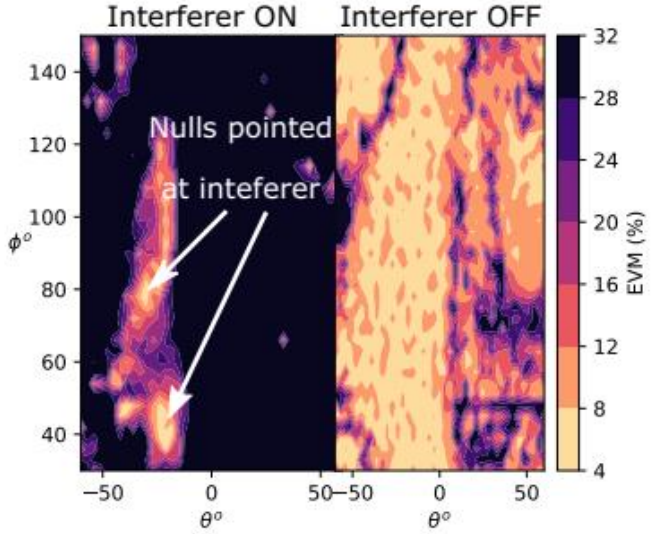
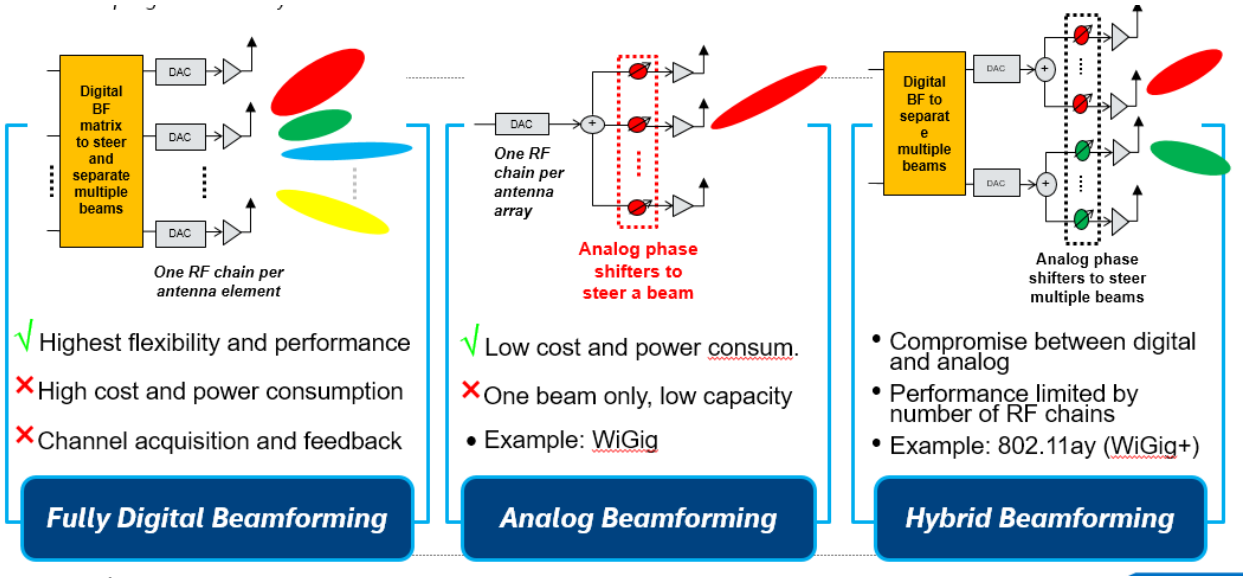


Fig. 7. Measurement result of the example SDPAR hardware experiment showing EVM vs RX SDPAR beam steering angle with and without an interferer.

Source: B.Sadhu et all, "A Software-Defined Phased Array Radio with mmWave to Software Vertical Stack Integration for 5G Experimentation,' IEEE 2018 International Microwave Symposium

BEAMFORMING ARCHITECTURE

- Today most system use Analog/Hybrid beamforming
- Promising active research in low power digital beamforming



DEFENSE IS EVOLVING

Desired DoD Evolution Paths

DoD Evolution Area	Capabilities & Components	Intel Technologies
Human & Robot Collaboration	AI | ML Sensors IdAM Wireless Comms/ MEC Computer Vision	Nervana | DLIA Embedded sensors SGX SDR | ADC – DAC | 5G Advanced Wireless Technology Movidius | RealSense
Autonomous Systems: Self-organizing & Cooperative	AI | ML, Machine Vision Edge Processing Security Beamforming/M2M Wireless Comms Computer Vision	Nervana DLIA | NCS SDIS | SGX SDR | ADC – DAC |5G Advanced Wireless Technology Movidius | RealSense
C4ISR: Systems of Systems	AI | ML Edge Processing Advanced SW Integration Mesh Networking/mMTC Wireless Comms Computer Vision	Nervana DLIA BIOS level SW SDR | ADC – DAC |5G Advanced Wireless Technology Movidius | RealSense
AI Collaboration: Autonomous & Collaborative	AI | ML Edge Processing Advanced SW Integration Contested Spectrum/ SON Wireless Comms Computer Vision	Nervana DLIA BIOS level SW SDR | ADC – DAC |5G Advanced Wireless Technology Movidius | RealSense|Mobileye

FAILED MILITARY COMMS PROGRAMS WITH 5G TYPE COMMUNICATIONS REQUIREMENTS

2000's

- MESHED SENSOR NETWORKS
- V2V COMMUNICATIONS
- FULLY INTEGRATED COMMS
- CANCELLED: UNDER-PERFORMING & COST OVERRUNS

2000's

- SOFTWARE COMMUINICATIONS ARCHITECTURE (SCA)
- MOBILE AD-HOC NETWORK
- CANCELLED: UNDER-PERFORMING & COST OVERRUNS

2000's

- CONNECTED SOLDIER COMMS DEVICES
- PEER TO PEER COMMS.
- CANCELLED: UNDER-DEVELOPED, COST OVERRUNS

Desired Tactical Comms "Ask" in 2002

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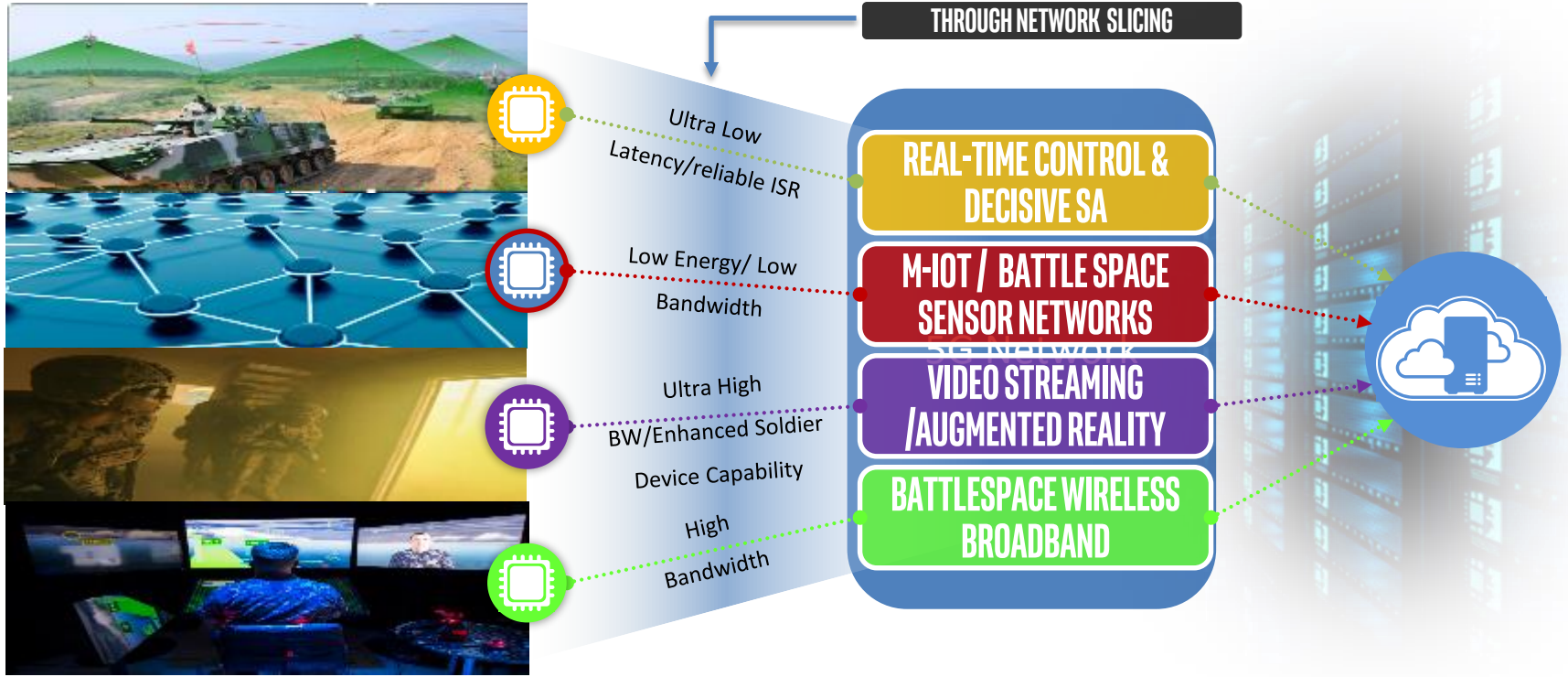
Desired Tactical Comms "Ask" in 2018

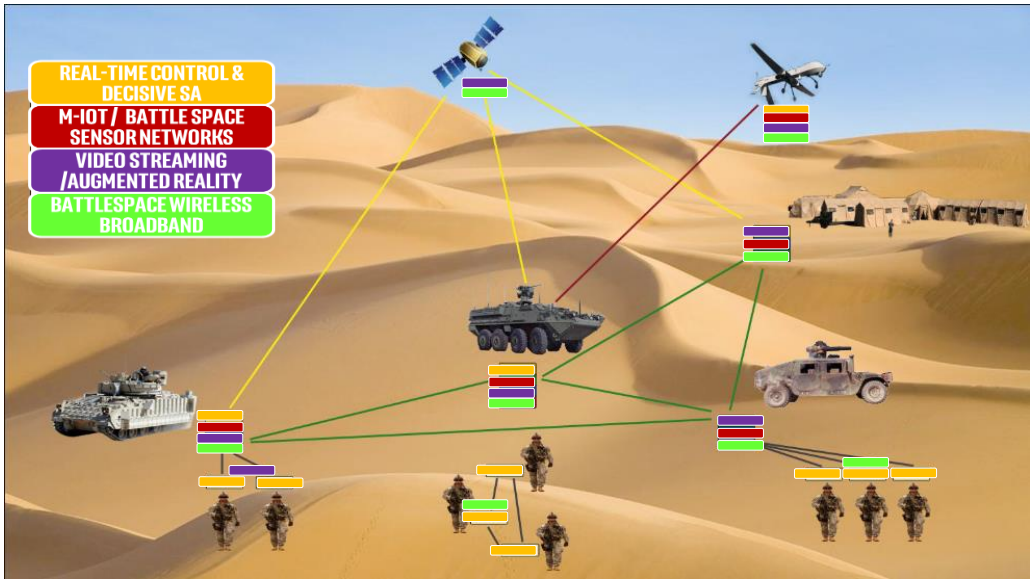
5G Technology can provide the "Answer to the Ask"

5G TECHNOLOGY: TACTICAL NETWORKS CAPABILITY ASK



TACTICAL RADIOS & TACTICAL NETWORKS CAPABILITY MAPPING

- Wireless Communication and Networks are critical aspects of the enabling technologies.
- Secure communication between generations of platforms, ground stations, NTM, as well as human and autonomous actors in a contested environment is a critical enabling technology of the **kill web**.
- Technologies that enable adaptive frequency allocation and spectrum management, flexible radio protocol selection, interference sensing or jamming avoidance all build on a software defined radio architecture(end to end with edge computing) are the building blocks that will provide a virtualized, secure and reliable communications for Blue Force actors.



MOSAIC BUILDING BLOCKS OF 5G	CAPABILITIES & COMPONENTS (15+ YEAR DOD ASK)	INTEL PRODUCTS & TECHNOLOGIES TO ANSWER "THE ASK"
MILITARY COMMUNICATIONS & NETWORKING NEEDS	FREQUENCY AGILITY V2V/ V2(SOLDIER) COMMS MASSIVE MIMO SELF HEALING CONNECTIVITY SDR ARCHITECTURE NETWORK SLICING	MEC, NFV FLEXRAN, FLEXCORE 5G RAN HW: 5G SMALL CELL DCC, 5G PROTOYPING, NETWORK SLICING PROGRAMMABLE SDR'S (FPGA) RF MODEMS DATA CENTERS, CLOUD COMPUTE

5G INFRASTRUCTURE BUILDING BLOCKS

ACCESS

- 5GNR RAT @ 28GHz, 39Ghz and 3.5 GHz
- MIMO
- Custom Si for Baseband and Radio
- FlexRAN Reference Software
- vCCAP (Cable) Reference Software

EDGE & CORE

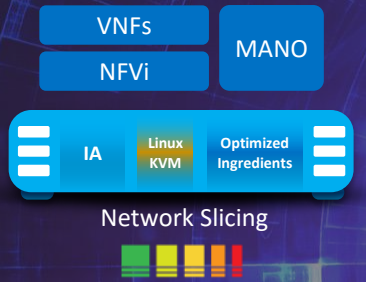
- FlexCore Reference Software
- MEC Source Libraries
- Network Edge Virtualization SDK for developers
- Next Generation CO Reference Architecture
- RSD

CAPABILITY ENABLERS

- Ciphering libraries
- CPRI over Ethernet FPGA Reference
- Transport Interworking software
- Visual Cloud (VCD) Libraries

NFV / SDN

Cloud Ready Networks



SCALABILITY & FLEXIBILITY FOR NETWORKING WORKLOADS

Intel® Xeon® Processor

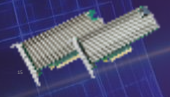
Intel® CORE® Processor

Intel® Atom™ Processor

Intel® Ethernet Controller

Altera® FPGA

Intel® 3D XPoint



Intel® QuickAssist

Intel® Quick Sync Video

Intel® Resource Director

MILITARY AGENCY ASK

INTEL COMMERCIAL PRODUCT DEVELOPMENT

AUTONOMOUS MILITARY VEHICLES

VEHICLE AUTONOMY

COMMERCIAL AUTONOMY

SMART BATTLE SPACE

SMART & CONNECTED

SMART CITES

MILITARY TACTICAL ANTENNAS

ADAPTIVE & ROBUST

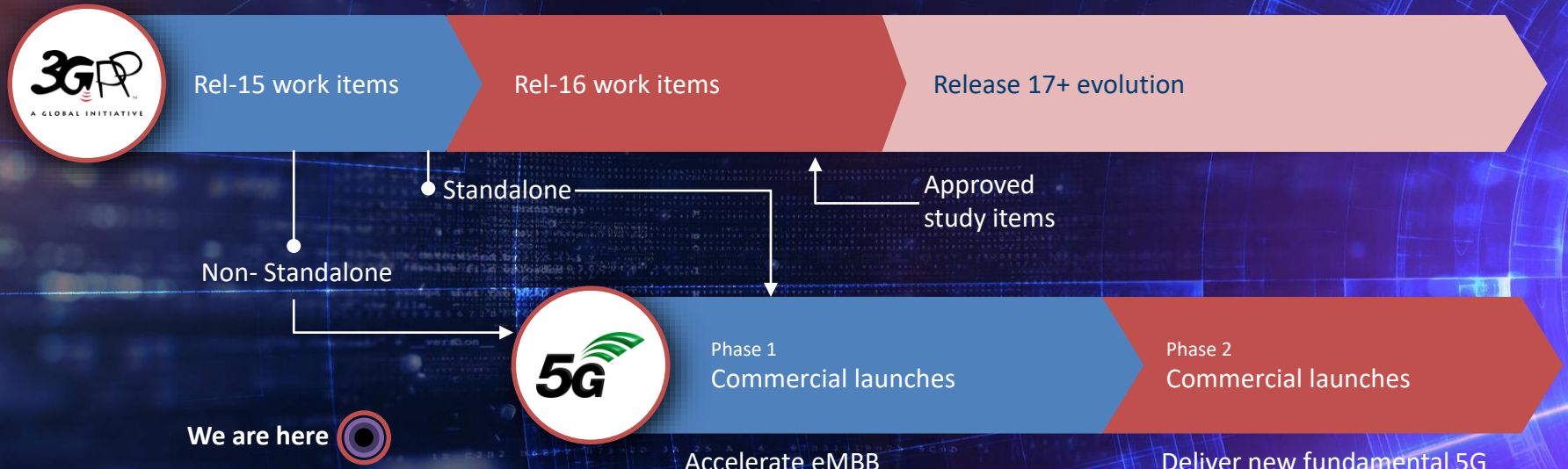
ADVANCED 5G BEAMFORMING MIMO ANTENNAS

CONCLUSIONS

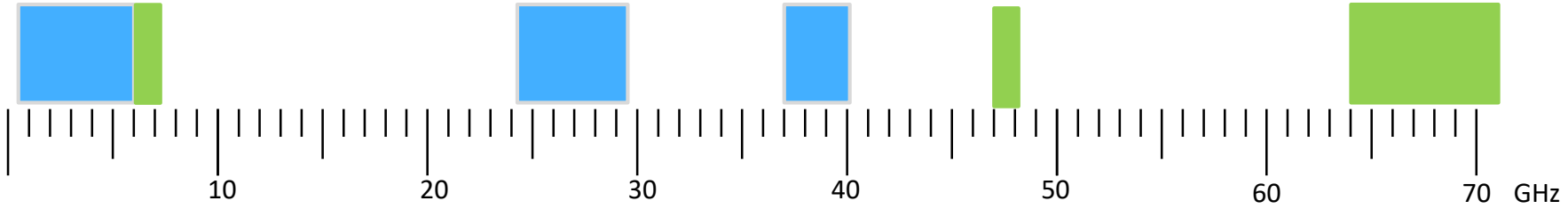
- 5G communication systems will offer novel features that will enable new markets, Including Military and first Responder Markets
  - URLLC, MMTC, LAA, network slicing, network function virtualization
- 5G radios/modems are very complex engines with high-investment development
- Opportunity to utilize **commercial 5G radio components as building blocks for tactical wireless communications** has finally arrived.

BACKUP

5G NR STANDARDS AND COMMERCIAL LAUNCHES



5G Spectrum Bands



FR1 450MHz-6GHz

- **"LTE band re-farming" [n1,n2,n3,n4,n5,n7,n8,n20,n28, n38,n41,n66…]**
  - Re-farming of existing LTE spectrum to 5G Supplementary uplink bands also defined.
- **"sub 6 GHz NR" [n77,n78,n79]**
  - Wider bandwidth providing a trade-off for 5G applications that require both capacity and coverage
  - Expected in first wave of 5G deployments. Some overlap with LTE UHB bands (B42,43,48 etc)

FR2 24.25-52.6GHz

- **mmWave [n257, n258, n260]**
  - Needed to accommodate very wide channel bandwidths for 5G applications requiring extremely high data rates
  - Requires mmWave antenna arrays

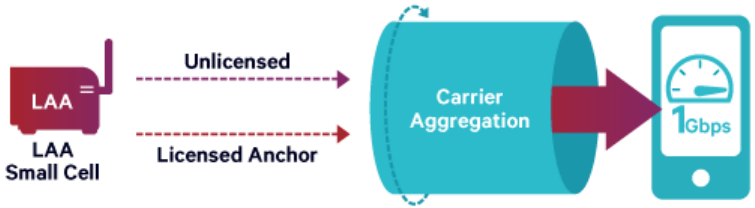
Unlicensed bands

- **5.9 – 7.1GHz**
- **47.2 – 48.2GHz**
- **64 – 71GHz**

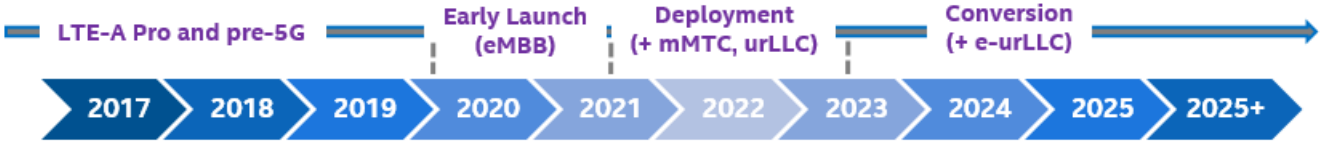
- 15GHz of new spectrum in mmWave band
- Need to combine licensed and unlicensed bands

LAA – LICENSED ASSISTED ACCESS

- Use of unlicensed spectrum in a cellular service to increase throughput
  - Anchor and high priority traffic on the licensed band
- Same Carrier Aggregation (CA) concept already in use in LTE/5G
  - In 3GPP since Release 13, with further improvements
- Fair coexistence in the unlicensed channel is provided by a region-specific listen-before-talk (LBT) capability to ensure channels are clear before transmission



Latency/Reliability Profile Classifier



Low to moderate requirements
(**Class A** reliability/latency profile, 10e-3 BLEP, and > 15 msec latency)
Sample example use cases:

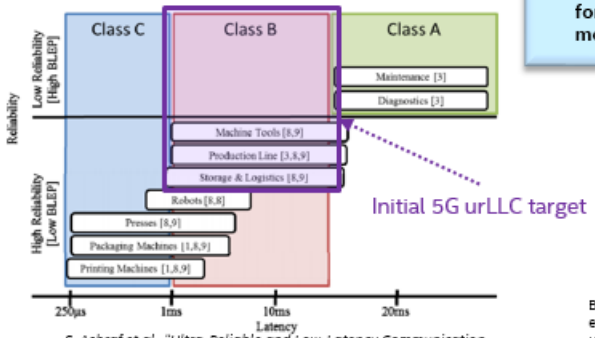
- ✓ **Remote operation targeting worker safety** (mining, construction, harbors)
- ✓ **Remote management** (surveying and inspection)
- ✓ **Logistics tracking**
- ✓ **Oil and gas remote monitoring, and optimization**
- ✓ **Condition monitoring**
- ✓ **Mobile robotics and Automated Guided Vehicles (AGV)**
- ✓ **Massive data transfer for predictive maintenance and diagnostics**

Complex requirements
(**Class-B** reliability/latency profile, 10e-5 BLEP, and ~ 1-10 msec latency)

- ✓ **Discrete control**
- ✓ **Process monitoring**

Extreme requirements
(**Class-C** reliability/latency profile, < 10e-7 BLEP, and < 1 msec latency)

- ✓ **Motion control (may include video/audio for remote monitoring/control)**



S. Ashraf et al., "Ultra-Reliable and Low-Latency Communication for Wireless Factory Automation: From LTE to 5G," IEEE, 2016

BLEP: Block Error Probability
eMBB: Enhanced Mobile Broadband
urLLC: Ultra-Reliable Low-Latency Communications
mMTC: Massive Machine-Type Communications

CHALLENGING THE TECHNOLOGY

INTEL'S 5G PROJECTS AROUND THE WORLD

50+ TRIALS WORLDWIDE

INTEL® 5G MOBILE TRIAL PLATFORM (MTP)

COMPLETE 5G FUNCTIONALITY IN A SMALL FORM FACTOR

MTP-NR is Intel's 5G CPE prototype for pre-commercial field trial testing & research

MTP-NR Features

- Ultra-high performance 5G architecture
- Up to 10Gbps throughput
- 2x processing capability vs. 2nd-Gen 5G MTP
- 28GHz and 39GHz bands
- 28GHz IF and RF for sub-6GHz
- Band support: 600-900Mhz, 3.3-4.2GHz, 4.4-4.9GHz, 5.1-5.9GHz
- 4x4 MIMO
- 16 antenna elements
- +11dBm power output
- 36 dBmi EIRP
- Based on state-of-the art Intel® Stratix® 10 FPGAs
- 3GPP NR early interoperability
- 200 MHz & 400MHz BW and up to 2Gbps Peak

INTEL® AUTOMOTIVE TRIAL PLATFORM (ATP): TESTING 5G ON THE GO

Multiple Successful Trials w/ Global Leaders

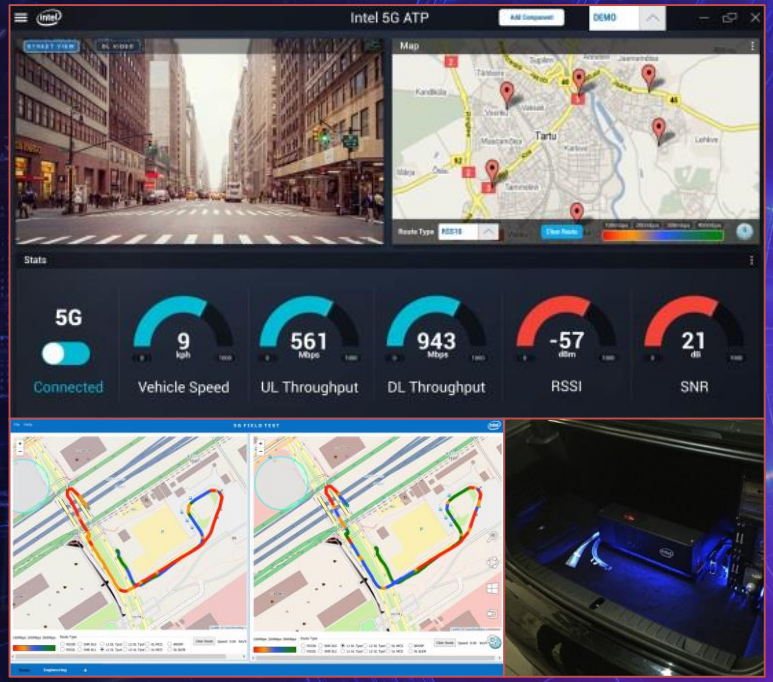
- Multiple trials w/ NTT DoCoMo*, China Telecom*, BMW*, Ferrari*, and others
- Applications range from remote bulldozer operation to windsurfing to autonomous driving

Automotive Trial Platform (ATP) Details

- 28GHz mmWave
- Intel® Core™ i7 Processor
- Powered by 5 Intel® Arria® 10 FPGAs
- ATP baseband is same as MTP 2nd gen

Technical Trial Results

- 5G at 28GHz mmWave operation using Intel 5G RFIC
- Integrated sub-6GHz and 28GHz RFFE operation w/ multi-panel antenna
- DL throughput of over 1Gbps; UL of 600 Mbps



- *Other names and brands may be claimed as the property of others.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