Millimeter-Wave RCN Kickoff Workshop
Summary of Discussion Points
Panels and Breakouts

Day 1

Panel 1 (90 min): State of mmW Technology, Challenges & Opportunities–Industry & Regulatory Aspects

Moderator: Akbar Sayeed

Panelists: Arun Ghosh (AT&T), Amitava Ghosh (Nokia-Bell Labs), Maziar Nekovee, (EU mmMAGIC), Ali Sadri (Intel), Ashwin Sampath (Qualcomm), and Ian Wong (National Instruments)

Scribes: Xinyu Zhang and Haitham Hassanieh

Format: 3 min opening remarks from the panelists followed by discussion.

Discussion points:

- Where is the 5G standardization process with regard to mmW?
- What are the initial use cases are the focus of technology development?
- What is the expected timeframe frame for initial products?
- Any major recent noteworthy breakthroughs?
- What are the major obstacles to mmW wave technology in 5G?
- Are there new regulatory developments, or in the making, that could influence mmW technology development?
- Current status and 2020 roadmap of industry-led European collaborative R&D and planned trial activities on 5G including mm-wave (mmMAGIC and mmMAGIC-II projects and others) in Europe towards 5G standards
- Current status/perspectives of 5G spectrum identification (which bands including those in mm-range) in Europe in preparation for WRC'19, what are the synergies and difference with the US
- Key outcomes on 5G mm-wave channel models from Europe
- How important is self-backhauling for mmWave deployments?
- Maturity of mmWave technology for form factor ready for UE's and CPE's?
- Will there be any difference between 28/39 GHz vs. 60/70 GHz mmWave technology?
- What are hardware-related obstacles to deployment of 5G?
  [It seems like there are issues with creating cost-effective hardware for even simple components like couplers and filters, not to mention the more complicated subsystems like antenna arrays and amplifiers. Perhaps some participants would have insight into these issues and ideas for overcoming them.]
- What are measurement-related issues?
  [As we have been discussing in the Channel Alliance, calibrations and measurement verification is much more important at mmWave frequencies. Verification of massive antenna systems presents a real challenge: how to do you efficiently test systems that can operate in an uncountable number of states? Test equipment is also a challenge: Because the electronics in the instruments is operating at the state of the art, it is complicated to characterize devices that are also operating at the state of the art, maybe NI can weigh in on this]\
- What air interface aspects should we pay special attention to so that mmw performance in NLOS and mobile scenarios is acceptable? (this will zoom in on the dynamic BF aspects, including fast adaptation, and how they could be supported).

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- What RF design and regulatory challenges need to be addressed to make mmw a viable technology for mobile devices? (this will cover PA design, antenna module design/placement and some discussion on MPE aspects. We could also talk a bit about spectrum sharing.)
- What do system modeling results tell us about anticipated performance? (people can talk about some of the channel models being used in 3GPP and associated link/system level results so far)
- Propagation channel measurements and modeling – what role do they play?
- What are some important system design, implementation, and test challenges in mmWave?
- How does mmWave technology stack up against other candidate technologies for 5G, e.g Massive MIMO, Network densification?
- What are the key research problems left to be solved to make mmW a true commercial success?
- What is path to 5G and what are the prerequisite for the next generation cellular network to get deployed.

Parallel Breakouts(60 min): Development of Technology Roadmap for mmW Research

Format: 5min opening remarks by the leaders to seed the discussion, followed by discussion.

- What are the key problems in the three technical areas that need to be addressed in the next 3-5 years?
- What kind of contributions can we expect from this RCN in the next 3 years?
- What are the problems for which cross-disciplinary collaboration will be critical?
- What do you hope will happen?
- What are you afraid will happen?
- What are you doing about it?

Breakout 1: Hardware: mmW hardware, antennas, digital hardware, prototypes and testbeds

Discussion Leaders: Jim Buckwalter and Ali Niknejad
Scribes: Vishal Saxena and Subhanshu Gupta

1) What are industry vs academic participant perspectives on phased array hardware and readiness?

i) State of art
ii) Perspectives for future research (Frequency scaling, etc)

2) What are key roadblocks to the current industry development of phased arrays, particularly for mobile (i.e. handset) applications? For backhaul? Will arrays only occupy a few niche applications in industry ultimately? Regulation/Cost/Power Considerations

3) Why does most mm-wave (prototype) hardware remain out of the hands of most academics? Can we find a way to prototype faster & cheaper to get it in the hands of more researchers? Is there a CAD gap?

4) What are the most critical barriers to producing a phased array in an industry versus academic environment? Man-power, cost of silicon. How can NSF-funded research lower barriers in the future?

5) Continuing hardware challenges:

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i) Low power architectures for digital beamforming

ii) Power Amplifiers – Peak efficiency/ Backoff efficiency is unsolved problem for CMOS technologies. Power density for lowering silicon area/costs. Heat dissipation.

iii) Frequency Scaling – Is there a rush to 140 GHz? 220 GHz?

iv) Full-duplex techniques for mm-wave; Is there an argument for channel estimation/control through full-duplex?

v) Mixed-signal for millimeter-wave. What are the academic challenges for DAC/ADC design for arrays? Is this a standalone problem any longer?

vi) Digital Signal Processing – Will software-defined arrays in DSP meet cost/power constraints?

vii) Alternative approaches for arrays: Multiplier arrays, Switched beam, Lens, Silicon photonics? Are these part of a portfolio ultimately?

viii) Foundry processes for phased arrays – Is there any role in NSF funded research when considering the CMOS processes required to push hardware capabilities? Is 65-nm CMOS the end of the road for mm-wave academic research?

ix) Are there enabling devices that might change the architectures/capabilities? For instance, low-loss mm-wave switches (GeTe) or low-loss passives.

x) Antenna design challenges, especially for mobile devices.

Prototyping at millimeter-wave bands to be limited by 1) packaging, 2) foundry, 3) CAD, and 4) man-power. In each of these items, the issue is cost and access to a technology or tool.

The complexity for phased arrays is likely to outpace the ability of academia to solve these problems. This suggests that we need to solve the prototyping hurdles with other research efforts.

- Power consumption/heat dissipation issues in RF hardware, ADCs/DACs, digital backend?
- Power amplifiers: challenges and opportunities?
- Switches, phase shifters, phased arrays, lens arrays: opportunities and challenges?
- RF integration, and RF + digital integration?
- Architectures for high-rate digital processing in the backend?

Breakout 2: Communication and Signal Processing Techniques

Discussion Leaders: Sundeep Rangan and Lee Swindlehurst
Scribes: Mai Vu and Cenk Gursoy

- What are the broad challenges, requirements and use cases that will drive CSP research in mmWave.
- What are the fundamental goals that we are trying to address that are not delivered by current systems?
- What are the main technical challenges?

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- What advances in hardware architectures / devices / RF will impact CSP and how do we leverage these? What oversimplifications
- does the CSP community make regarding hardware when studying mmWave systems and how can we address these?"
- What do we need and how can we benefit from related fields (e.g. information theory, optimization, signal processing, machine learning)?
- What are some promising strategies for reducing computational complexity of the digital backend?
- What are some promising strategies for reducing the complexity of the analog-digital interface?
- What would we like to accomplish in the next 3 years?
- How to address the propagation challenges, such blockage?

Breakout 3: Networking Techniques

Discussion Leaders: Ismail Guvenc and Marwan Krunz
Scribes: Allen MacKenzie and Nicolo Michelusi

1. Network/Node Discovery and Initial Coordination
    a. Computationally efficient beam finding and tracking algorithms
    b. Design of reference signal (pilot) in downlink
    c. Random access in uplink
    d. User-BS association and handover in a multi-BS environment
2. Scheduling and Resource Allocation.
    a. Time/frequency/spatial (MIMO/beamforming) resource allocation
    b. Impact of mmWave channel models on scheduling and resource Allocation
    c. Interference characterization
3. Network Architectures & Protocols
    a. Backhaul architecture
    b. Channel access protocols
    c. Multi-hop operation (routing protocols)
    d. Contention between multiple systems (game theory, reinforcement/machine learning)
    e. Mobility-resilient designs
    f. Heterogeneous coexistence in mmW bands (role of spectrum sharing)
4. Coverage/Capacity/Latency/Energy-Efficiency Tradeoffs
    a. Placement of base stations & cell distribution (stochastic geometry tools)
    b. Sleep-mode optimization
5. Testbeds and Experimentation
6. Networking Applications:
    a. Vehicular networks
    b. UAV networks
    c. VR/AR, Wearables
    d. Smart cities

- What are the key challenges for achieving multi-Gigabits/s end-to-end rates?
- What are the key challenges to achieving millisecond latency?
- What are the implications for cross-layer design?

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Day 2:

Readouts from Day 1 Breakouts (Discussion Leaders) to prime the Panel 2 Discussion (30min)

Panel 2 (90 mins): Cross-disciplinary Collaboration in mmW Research – Scoping the Landspace and Charting a Course for RCN Contributions

Moderators: Nada Golmie

Panelists: Marwan Krunz (Arizona), Sundeep Rangan (NYU), Charlie Zhang (Samsung), Ian Wong (NI), Mythri Hunukumbure (mmMAGIC), Amitava Ghosh (Nokia)

Scribes: Xinyu Zhang and Haitham Hassanieh

Format: opening 3 min statements from Moderator/Panelists followed by Discussion

Discussion points:

- What the big problems that will require cross-disciplinary problems?
- What kind of contributions can we expect from this RCN in the next 3 years?
- How do we facilitate cross-disciplinary collaboration?
- What are the key elements of successful cross-disciplinary collaboration?
- What are some common hindrances to collaboration that we need to be aware of?
- Collaborative research themes across hardware-comm./signal processing?
- Collaborative research themes across comm./signal processing/networking?

The 'cross disciplinary' term also refers to wider disciplines that can benefit from the mm-wave communications such as V2X, IoT, industry automation etc. There is already significant ongoing research in these verticals. The importance of such collaboration is recognized in the proposed mmMAGIC-II project and it strives to address the challenges in these verticals, with key players as project partners. One example is using mm-wave for communications in disaster and emergency situations, with drones, robots, emergency vehicles and crew all connected through mm-wave. It is important to forge this kind of ties with the key players in these vertical industries and RCN. This will enable us to understand the real requirements, development time scales and challenges in these verticals. Specific discussion points:

- How can we effectively engage with these vertical industries, grasping their requirements and challenges and then looking to develop solutions
- At least in some of the verticals, there is already disparity in the wireless technology adaptation (e.g, in V2X, preference for 802.11p in US, for LTE in China). Should we try to avoid this in other verticals or we should accept this and let the market decide the best-fit technologies?

- What is the role of academia vs.government vs. industry in terms of end-to-end large-scale testbeds and prototyping in mmWave research?
- How do you see the mmWave RCN working with the PAWR initiative?
- Is there value in a DARPA grand challenge around mmWave technology?