mmWave Technology Evolution
From WiGig to 5G Small Cells

Ali Sadri
Intel Corporation
Director of mmWave Standards & advanced Technology
CEO & Chairman of WiGig Alliance
June , 2013
Wireless Connectivity in Our Lives
What Do We Have in Common?

- Smaller Form Factor!
- Limited Connectors!
- Limited Data Storage!
- Larger Media Contents!
- Fast Upload / Download!
- Always Connected!
Available Unlicensed Frequency Bands

- The 60GHz band offers 5 – 9 GHz of unlicensed bandwidth across most Geographies.
  - 2.16GHz Bandwidth per channel
- Compared with:
  - ~90 MHz in ISM band (2.4GHz band)
    - 20Mhz – 40MHz per channel
  - ~500 MHz in UNII band (5 GHz band)
    - 20Mhz – 160MHz per channel

![Available Unlicensed Frequency Bands Diagram]

- Bands are drawn to scale
mmWave Challenges

- It doesn't go through the Wall!
- High Power, Needs a Fan!
- Beam Forming does not Work!
- 60 GHz Kills You!
- Works only in LOS!
- Path Loss is High!
- It's a Snake!
- It's a Wall!
- It's a Tree!
mmWave Challenges

WiGig is Here!

- High Power, Needs a Fan!
- It doesn’t go through the Wall!
- Beam Forming does not Work!
- It’s a Snake!
- It’s a Wall!
- It’s a Tree!
- Path Loss is High!
- Works only in LOS!
- 60 GHz Kills You!
WiGig Usage Models

Instant Wireless Sync
- IP based P2P applications
- Wireless I/O
- Media HotSpot

Wireless Display
- HD streams over HDMI or DP
- CE & PC & HH usages
- Hulu, IPTV, YouTube

Wireless Docking
- Combination of Wireless display, sync and I/O

Access
- WiFi, IEEE TGad
- 3G/4G, Offload
- Small Cell Access & Backhaul

Peer to peer

Kiosk Sync & Nano small Cell

Wireless Display

Cordless IO

Distributed peripherals

Access, Offload, Backhaul
WiGig enabled chipsets will be over a BILLION units; almost 40% of all multiband chipset
WiGig Alliance Members

Board of Directors

Contributors
What is WiGig?
WiGig System Attributes

MAC
• Compatible with legacy 802.11
• Includes new PBSS mode (point to point)
• Includes new channel access (TDMA)

PHY
• Includes Single Carrier rates up to 4.62Gbps
• Includes OFDM rates up to 6.756Gbps

PAL
• WiGig Serial Extension (WSE), USB payload over WiGig link
• WiGig Bus Extension (WBE), PCIe over WiGig link
• WiGig SDIO Extension (WSD), SDIO payload over WiGig link
• WiGig Display Extention (WDE), HDMI and DP over WiGig link

Industry Support
• Royalty free 60GHz standard with wide industry support
• IEEE 802.11ad publication by EOY 2012

Interoperability
• Wi-Fi certified, Merged with WiFi Alliance

Regulatory
• Harmonized around the world
• ITU-R recommended
WiGig: Evolution of a mmWave Technology

Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2
---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----
2009 | 2010 | 2011 | 2012 | 2013

- May 7: WiGig Alliance is Born
- May 10: Wi-Fi Alliance® and WiGig announce cooperation. 802.11ad is formalized.
- Oct 24: World’s First WiGig Technology Plugfest
- September 13: Multigigabit Wireless Docking Demoed at IDF 2012
- January 7: WiGig Takes Center Stage at 2013 International CES

- December 16: First Specification
- June 30: Certification Ready Spec Published
- April 5: 120+ Companies At WiGig Office Opening in Taipei
- March: Merger Agreement signed with Wi-Fi Alliance®
- January 31: First Joint Plugfest for WiGig - Wi-Fi Alliance®
WGA Merging with WFA

- Prevent ecosystem fragmentation, duplication and thus accelerate development & adoption
- Prevent confusion by delivering a high-impact integrated branding & communication
- Leverage existing brand recognition of WFA for MACPHY cert, USB for WSE cert and VESA for WDE cert
- Make efficient use of resources (people, travel, fees, certification, etc.)
WiGig Usage Models

**Instant wireless sync**
- IP based P2P applications
- Wireless I/O
- Media HotSpot

**Wireless Display**
- HD streams over HDMI or DP
- CE & PC & HH usages
- Hulu, IPTV, YouTube

**Wireless Docking**
- Combination of Wireless display, sync and I/O

**Access**
- WiFi, IEEE TGad
- 3G/4G, Offload
- Small Cell Access & Backhaul
Exponentially Increasing Capacity

• Multi-company forecast of rapid growth of total traffic:\n
![Bar chart showing exponential growth in total traffic from 2011 to 2015.]

• By 2016: Over 10B connected devices and Global mobile data traffic will reach 10.8 exabytes/month. ²

1. ITU-R Report M.2243:
mmWave Advantage

Capacity Increase Technique

Densification (D)

Bandwidth & Throughput (B)

Spectrum Efficiency (S)

mmWave Advantage

Inherent Shorter Range and Beamsteering Mitigate Interference

mmWave Bands Support Multi-Gbps Rates

Beamsteering and MU-MIMO Techniques Support PtP and PtMP in Same Frequency Band

Capacity Increase = D x B x S > 1000
Small Cell Components

Cellular Backhaul

Cellular Access  Wi-Fi Offload
mmWave Capable Small Cells (MCSCs)

Cellular Backhaul
- LTE - Bands
- 6-42 GHz
- 60 GHz (Modified WiGig MAC-PHY)
- E-Band (70, 80 GHz)

Cellular Access
- LTE, 4G & 4G+
- Multi-Gbps mmWave

Wi-Fi Offload
- 802.11ac
- WiGig / 802.11ad

Licensed
Unlicensed
The mmWave Enabled HetNet

High-rate access to mobile devices
- Steerable, high gain TX and RX antennas at booster eNB
- Steerable, lower gain TX and RX antennas at UE
- Licensed

Short-hop fronthaul link
- Steerable, high gain TX and RX antennas
- Licensed/unlicensed

Long-hop backhaul link E-band
mmWave Small Cell vs. Modern LTE Femto

Cell throughput comparison

LTE average: 50 Mbps/cell MU  
mmWave Small Cell: Up to 4 Gbps SU, 50 Gbps MU

Energy efficiency / beamwidth comparison (green radio)

LTE Femto antenna HPBW: 70-90°  
mmWave Small Cell antenna HPBW: 2-3°

New feature: Intelligent beam control

- Per-beam power control to meet QoS and FCC requirements
- Beam steering / Beam tracking and Precise user positioning

Tx Power = 26 dBm
G = 5-8 dBi  
θ = 70-90°  
Illumination spot: whole area

Tx Power = 25 dBm
G = 30-33 dBi  
θ = 2-3°  
Illumination spot: 2-3 m

x1000 throughput increase

x30 Energy efficiency increase
Long Term Goal, MU-MIMO
The Search for Alternate Spectrum

Current IMT bands

- 24 GHz Band Licensed
- LMDS Band Licensed
- 40 GHz Band Licensed
- 50 GHz Band Licensed
- 60 GHz Band Unlicensed
- 70-80 GHz Bands Minimal/Licensed

Increasing Bandwidth
Decreasing Range

MS: Mobile Service allocation
Possible Frequency bands for mmWave Access

- **ITU**: MS, FS, FSS
- **US**: 27.5 - 29.5 GHz
- **EU**: 26.5 - 29.5 GHz
- **KOREA**: 27 - 29.5 GHz
- **CEPT**: 37 - 39.5 GHz
- **RUSSIA**: 36 - 37 GHz
- **JAPAN**: 38.06 - 39.48 GHz
LMDS band plan in the US

28 & 31 GHz Band Plan

Two LMDS Licenses per BTA

Legend

- PSS - Primary Service
- FSS - Fixed Satellite Service
- GSO - Geostationary Orbit
- NON-LTTS - Non-Local Television Transmission Service
- MSS - Mobile Satellite Service
- NGSO - Non-Geostationary Orbit

Co-primary with incumbent point-to-point licensees
39 GHz band plan in the US
mmWave Path loss Comparisons

**Note:** Assumption is that we are using the same TX/RX antennas **gain for all bands**. But it means that antenna size for 30GHz will be two times larger than for 60GHz (aperture size by 4 times bigger!). In the case of hard limitations on antenna size additional **6dB** advantage will be lost for low frequency bands.
CDF Vs SNR Comparison

SINR comparison for different frequency bands

For 100 meters deployment 30 GHz outperform 60GHz on median level by 1.2 dB.
For 200 meters deployment 30 GHz outperform 60GHz on median level by 2.4 dB.
Achieving Compatibility with Legacy Systems

Beam Refinement Alg
High Rate Phy
Acquisition and Train

Time Base
Frame Structure
Scheduler
Access Protocols

mmWave Enabled 5G
Possible LTE-Assisted Handoff

Anchor eNB tracks UE relative to Booster eNB

Anchor / Booster Negotiate Handoff

UE Conducts Beamforming Training and Scheduling. UE keeps its connection with the anchor eNB for C-plane data and delay sensitive U-plane data.
Early Simulation result

• For SU-MIMO mode mmWave communication system has shown 5.4 Gbps/cell throughput (90 Mbps/UE for 60 UE/cell) for 50 m Small cell size. (No overhead assumed)

• For MU-MIMO mode simulations, under reasonable assumptions, mmWave Small cell demonstrates 59 Gbps/cell throughput (about 1 Gbps/UE for 60 UE/cell) for 50 m Small cell size. *(matching analytical results previously presented)*

• The system without intelligent power transmit power control may violate FCC requirements on signal power density. ITPC scheme prevents this violation without substantial system performance metrics degradation *(SW controlled EIRP/UE)*
Simulation results: MU ranks for MU-MIMO modes

![Graph showing MU ranks for different modes]

- LOS, MU-MIMO, MaxRnk-1@UE, None-CoMP, SVD, PerfChMeas
- 8x64, 25 dBm, w/o power control (FCC violation)
- 8x64, 25 dBm, power control (FCC compliance)
- 8x32, 22 dBm, power control (FCC compliance)
A new generation of cellular systems evolves every 5-7 years

Beyond 4G technology research and development begins now!
Summary

- WiGig is a multi Gigabit wireless standards and technology that enhances the usability of WiFi beyond connectivity and networking.
- Multi Gigabit connectivity imposes higher capacity to the existing Cellular systems.
- To increase capacity, increased small cell density, higher throughput and spectral efficiency systems are required.
- mmWave enabled HetNet can significantly increase the system capacity.
- WiGig as a proven mmWave technology can be extended to mmWave cellular systems.
- New generations of cellular systems evolve every 5-7 years, mmWave technology is a great candidate for beyond 4G systems.