Enhancing Throughput in 802.11

Richard van Nee
Qualcomm
Breukelen, The Netherlands
rvannee@qualcomm.com

Example of large scale WiFi network: Super Bowl

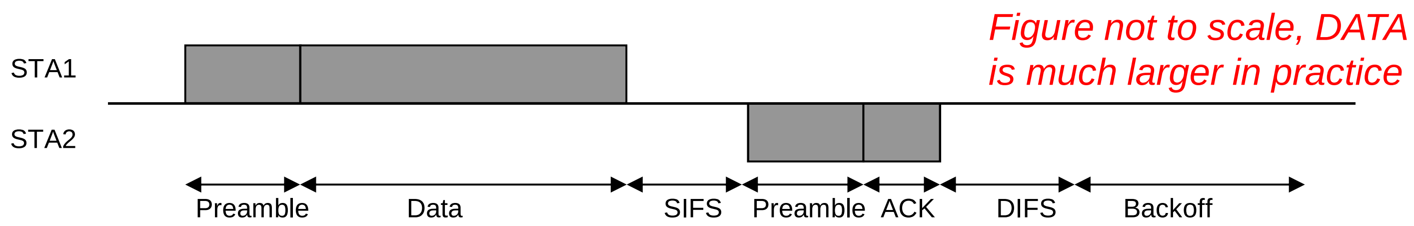
- 604 access points provided free WiFi at 2012 Super Bowl in Indianapolis
- 12,946 attendees (19%) connected to the network at some point during the game.
- Maximum of 8,260 simultaneous connections
- Directional Antennas were used to illuminate parts of the stadium from above, minimizing interference to neighboring cells

“As cellular and WiFi get congested, fans might actually have to *watch* the game.”

http://arstechnica.com/features/2012/08/why-your-smart-device-cant-get-wifi-in-the-home-teams-stadium/

IEEE 802.11 MAC

- Time Division Duplex
- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA, also known as *Listen Before Talk)*



- SIFS: Short Inter Frame Spacing: time between end of packet and start of acknowledgment
- DIFS = SIFS + 2 slot times
- Backoff: uniformly distributed number of slots between 0 and CW (Contention Window)
- CW = aCWmin initially, increases for retries until aCWmax
- Throughput efficiency for single transmitter-receiver pair = Tdata/(2Tpreamble+Tdata+Tack+SIFS+DIFS+Tbackoff)
  - Typical efficiency is about 75%
- Distributed MAC provides easy scaleability of 802.11 networks without any centralized coordination
  - 2 neighbor networks in the same channel that are close together will automatically share the total capacity
  - Key to success of 802.11

Ways to Increase Throughput

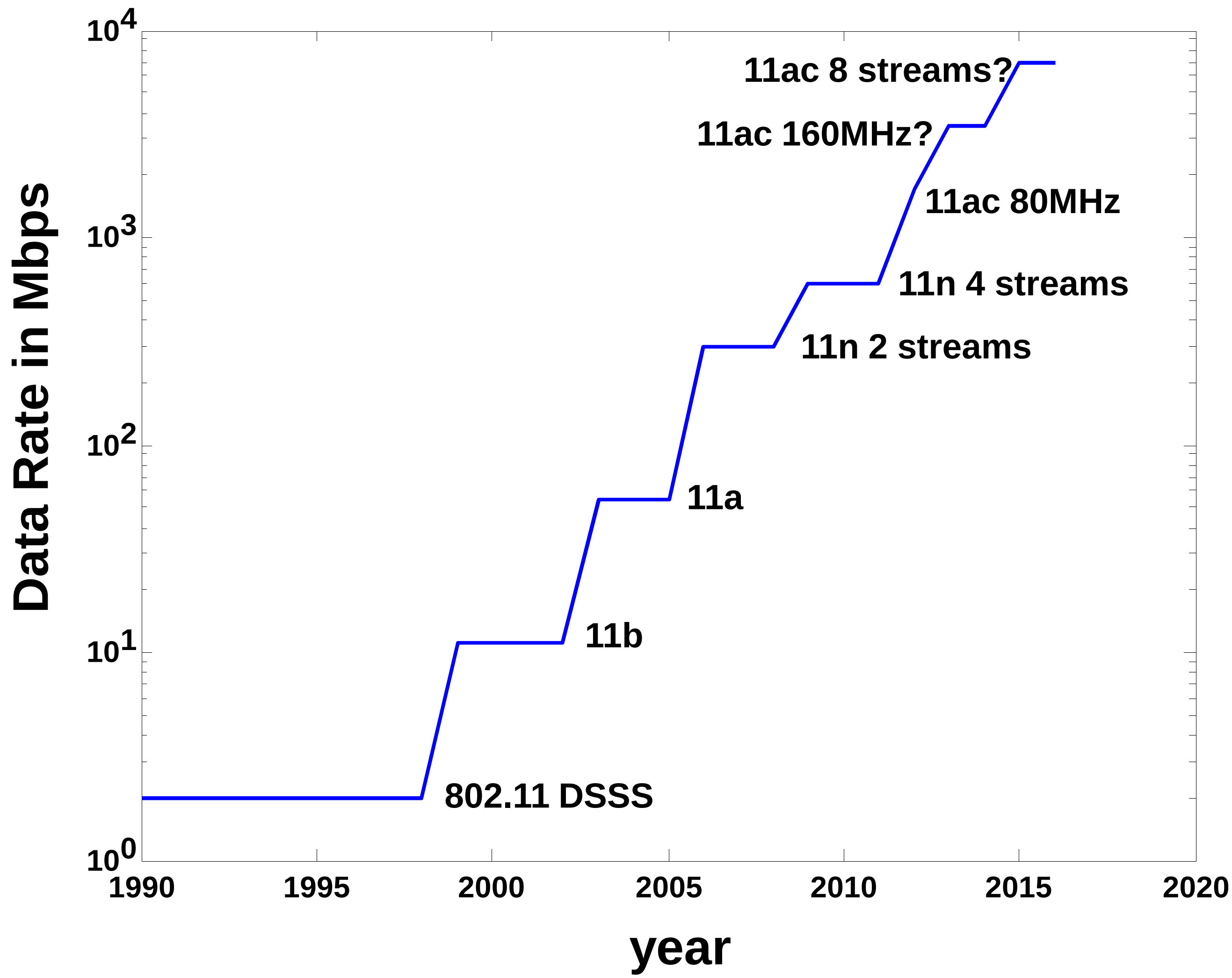
- More bandwidth
  - 40MHz channels introduced in 11n
  - 80MHz and 160MHz channels introduced in 11ac

- Higher signal constellation
  - 256-QAM introduced in 11ac

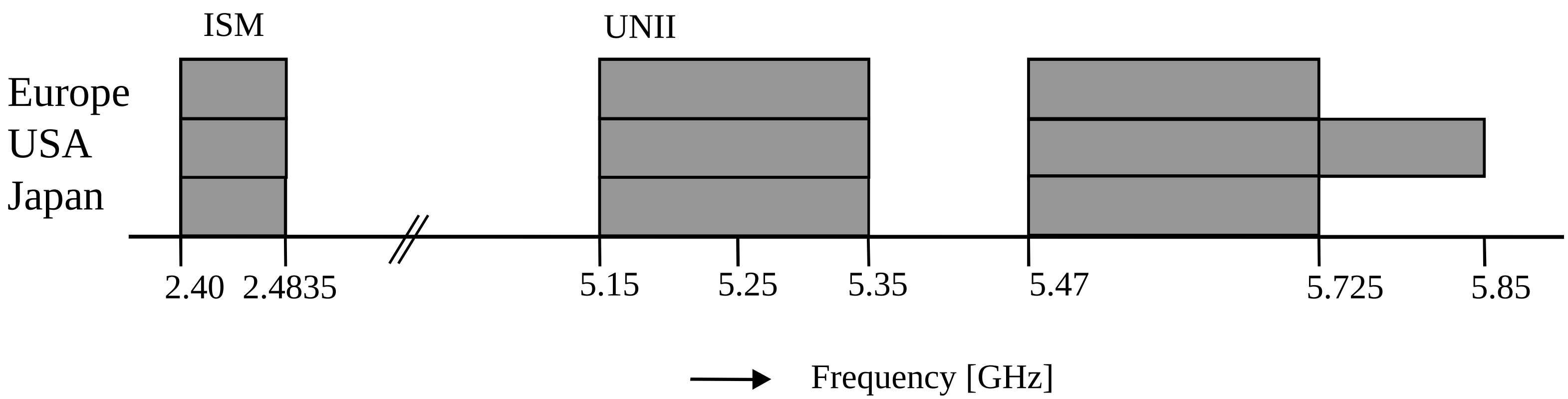
- More spatial streams (SU-MIMO or MU-MIMO)
  - Up to 4 streams in 11n and 8 streams in 11ac

- Reduce protocol overhead
  - Aggregation to make data portion of packets much larger than total PHY+MAC overhead

802.11 Data Rate Growth



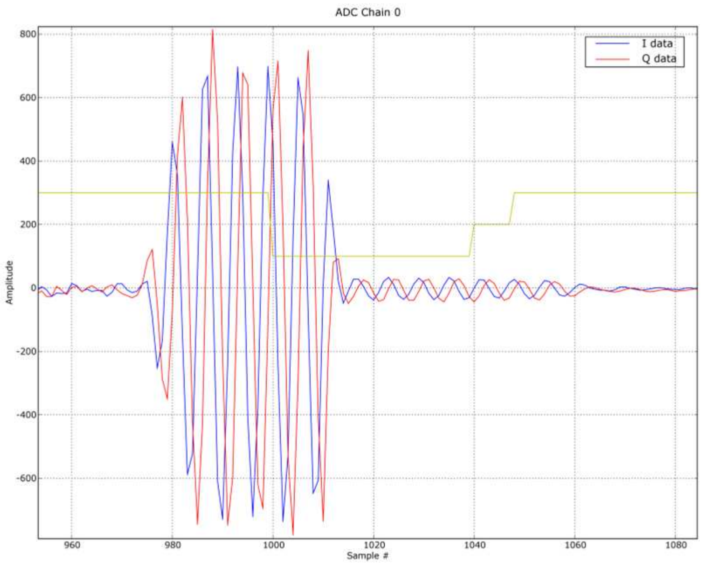
Wireless LAN Spectrum in 2.4 and 5 GHz



- 83.5 MHz in 2.4 GHz : 3 or 4 channels
- 455 MHz in 5 GHz : 19 20MHz channels (or 9x40, 4x80, or 2x160MHz channels)
- Note that FCC recently excluded transmission in any channel overlapping the weather radar band 5600-5650 until new coexistence rules are developed

Radar Detection

- Radar detection is required in 5.25 to 5.725 GHz
  - WiFi is not allowed to use a channel where radar is detected
  - Example of cognitive radio



- Measured radar pulse from KNMI weather radar in De Bilt at 5666MHz
- Pulse detected inside Breukelen Qualcomm office at 14km distance

802.11 Wireless LAN Standards (1)

- 2.4 GHz
  - IEEE 802.11b
    - 11 and 5.5 Mbps using Complementary Code Keying
    - 2 and 1 Mbps using Barker code
  - IEEE 802.11g
    - Brings 802.11a OFDM in 2.4 GHz band
    - Defines some mechanisms for coexistence between 802.11b and 802.11a
- 5 GHz
  - IEEE 802.11a
    - OFDM, 6 to 54 Mbps
  - IEEE 802.11n
    - MIMO-OFDM, 6.5 to 600 Mbps
  - IEEE 802.11ac
    - Single User and Multi-User MIMO, 6.5 to 6933 Mbps

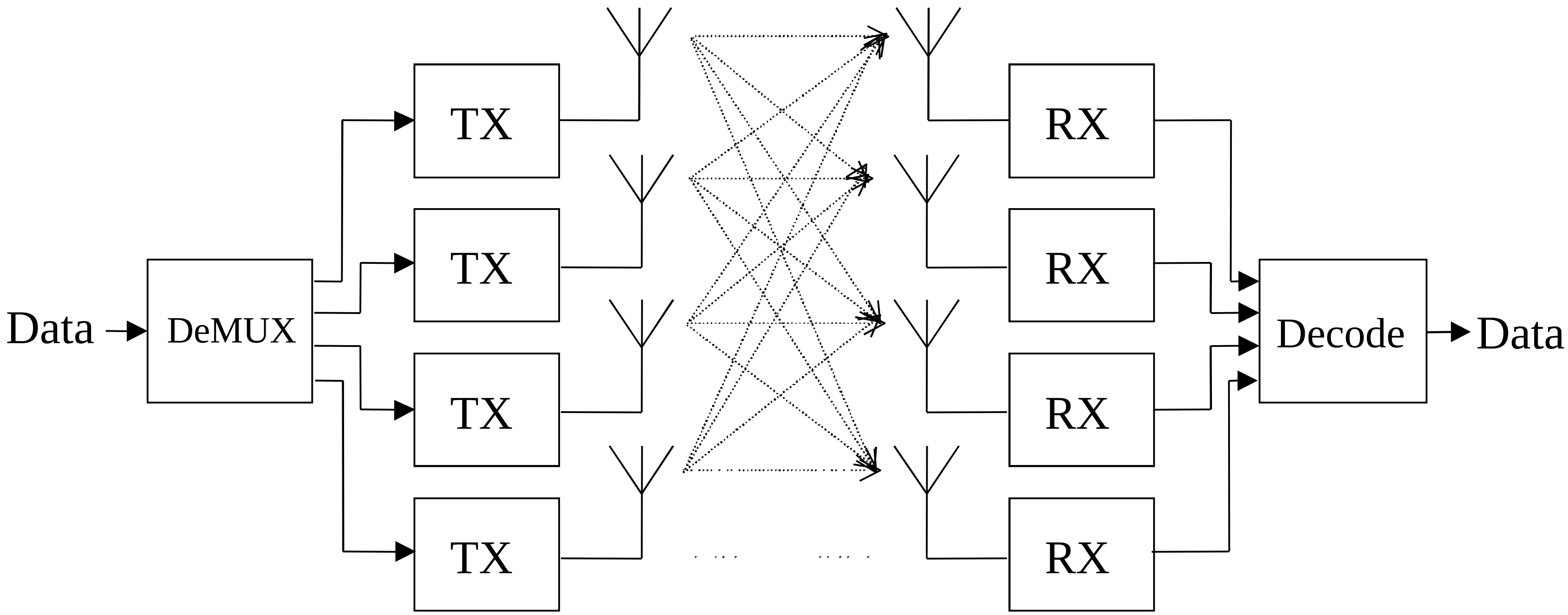
802.11 Wireless LAN Standards (2)

- Below 1GHz
  - IEEE 802.11ah (under development)
    - OFDM, MIMO-OFDM, MU-MIMO
    - Data rates from 150kbps to 86Mbps
    - Low data rates targeted for low power sensors
      - Sleep modes for multi-year battery operation
  - IEEE 802.11af (under development)
    - Downclocked 11ac 40MHz mode in TV white space channels fo 6, 7,or 8MHz
    - Data rates from 800kbps to 106Mbps
- 60 GHz
  - IEEE 802.11ad
    - Single carrier and OFDM
    - Data rates from 27Mbps to 6756Mbps
    - Low range only, sensitive to signal blockage

802.11ac

- 5GHz band only
- 20, 40, 80, 160MHz channels
- Single-User MIMO defined up to 8 streams
- Multi-User MIMO defined up to 4 streams from 2 to 4 different clients
- Explicit channel feedback for both Single-User and Multi-User beamforming
- 256-QAM
- Aggregation up to 1MB (16kB in 11n)
- Peak data rate of 6933Mbps for 8 streams in 160MHz
  - 433Mbps for a single antenna device (like most smartphones) in 80MHz
  - 1733Mbps for a 4-antenna / 4-stream device in 80MHz

Multiple Input Multiple Output (MIMO)



- Increase data rate without increasing bandwidth by transmitting multiple simultaneous data streams from different antennas

MIMO-OFDM Basics

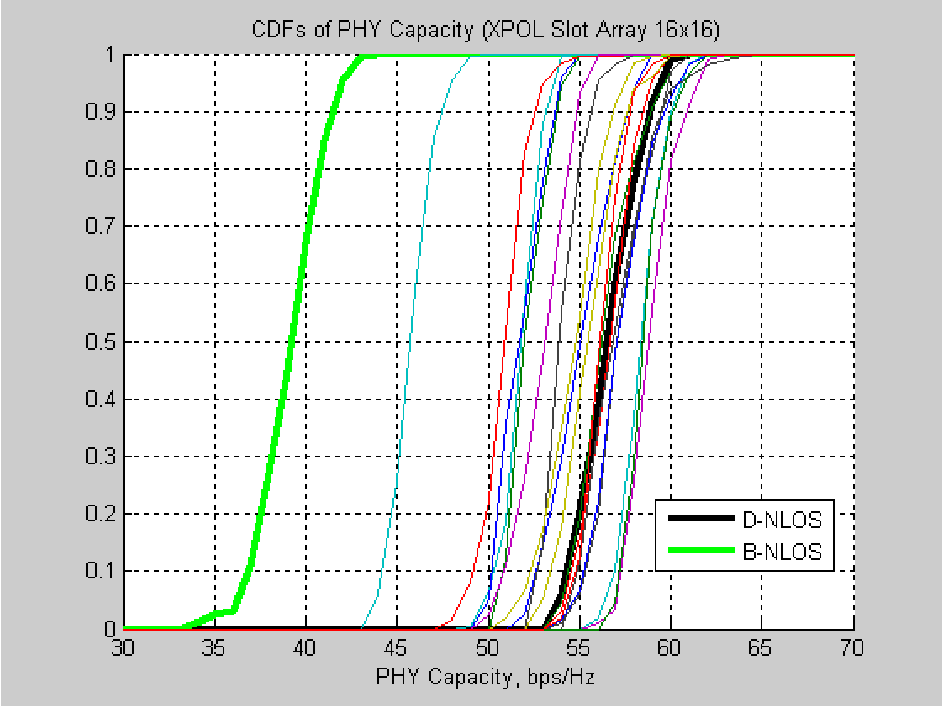
- With multiple antennas at *both transmitter and receiver*, capacity increases by a factor that is minimum of number of TX/RX antennas[1]
- E.g., with 2 TX and 2 RX, users can transmit 2 times the data rates compared to a single antenna link by using spatial division multiplexing
- Multiple Input Multiple Output (MIMO) capacity is larger in presence of multipath $\Rightarrow$ MIMO exploits multipath rather than fighting it
- For non-MIMO rates, multiple TX/RX antennas increase range by a combination of transmit diversity and optimal receive diversity
- Orthogonal Frequency Division Multiplexing (OFDM) is used to avoid intersymbol interference, which simplifies implementation of MIMO[2]

[1] *G.G. Raleigh and J.M. Cioffi, 'Spatio-Temporal Coding for Wireless Communications,' GLOBECOM '96, London, November 1996, pp.1809-1814.*

[2] *G.G. Raleigh and V.K. Jones, 'Multivariate Modulation and Coding for Wireless Communication,' IEEE Journal on Sel. Areas in Comm., Vol. 17, No. 5, May 1999, pp. 851-866.*

Measured MIMO Capacity

- Channel measurements using a 16 antenna array at both sides of a link shows capacity around 50 bps/Hz
  - For comparison: UMTS peak capacity is 0.4 bps/Hz (2Mbps in 5MHz channel)
  - 11n 4 streams peak capacity is 15 bps/Hz (600Mbps in a 40MHz channel)



Each CDF curve reflects a different test location

Capacity calculation was performed as follows:

1. Calculate MMSE post-processing SINR at each tone, assuming 24 dB SNR per antenna.
2. Convert SINR at each tone to capacity.
3. Average capacities across all tones across 20 MHz BW

Note: Green and Black curve are capacities derived from channel models, all other curves are based on measurements

Multi-User MIMO

- Access Point transmits packets to multiple clients ***simultaneously***
- Network throughput is increased rather than increasing the maximum throughput for a single link
- 802.11ac defines MU-MIMO for up to 4 MU streams to 2 to 4 MU clients

Potential New 802.11 Standards

- UWB 3-9GHz
  - Similar data rates and ranges possible as 11ad

- 5GHz 11ac Enhancements
  - Uplink MU-MIMO

- Cellular data offload
  - Specify interworking mechanisms between cellular and WiFi networks