# 2011 1st semester MIMO Communication Systems

# #12: Standardization of MIMO Systems

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# Schedule (2nd half)

| | Date | Text | Contents |
|---|---|---|---|
| #7 | May 31 | A-5 | MIMO receiver |
| #8 | June 7 | A-3, 4 | MIMO transmitter |
| #9 | June 14 | B-9 | Adaptive commun. system |
| #10 | June 21 | A-6, B-14 | Multi-user MIMO |
| #11 | June 28 | B-15, 16 | Distributed MIMO networks |
| #12 | July 5 | | Standardization of MIMO |
| | July 12 | | Final Examination |

# Agenda

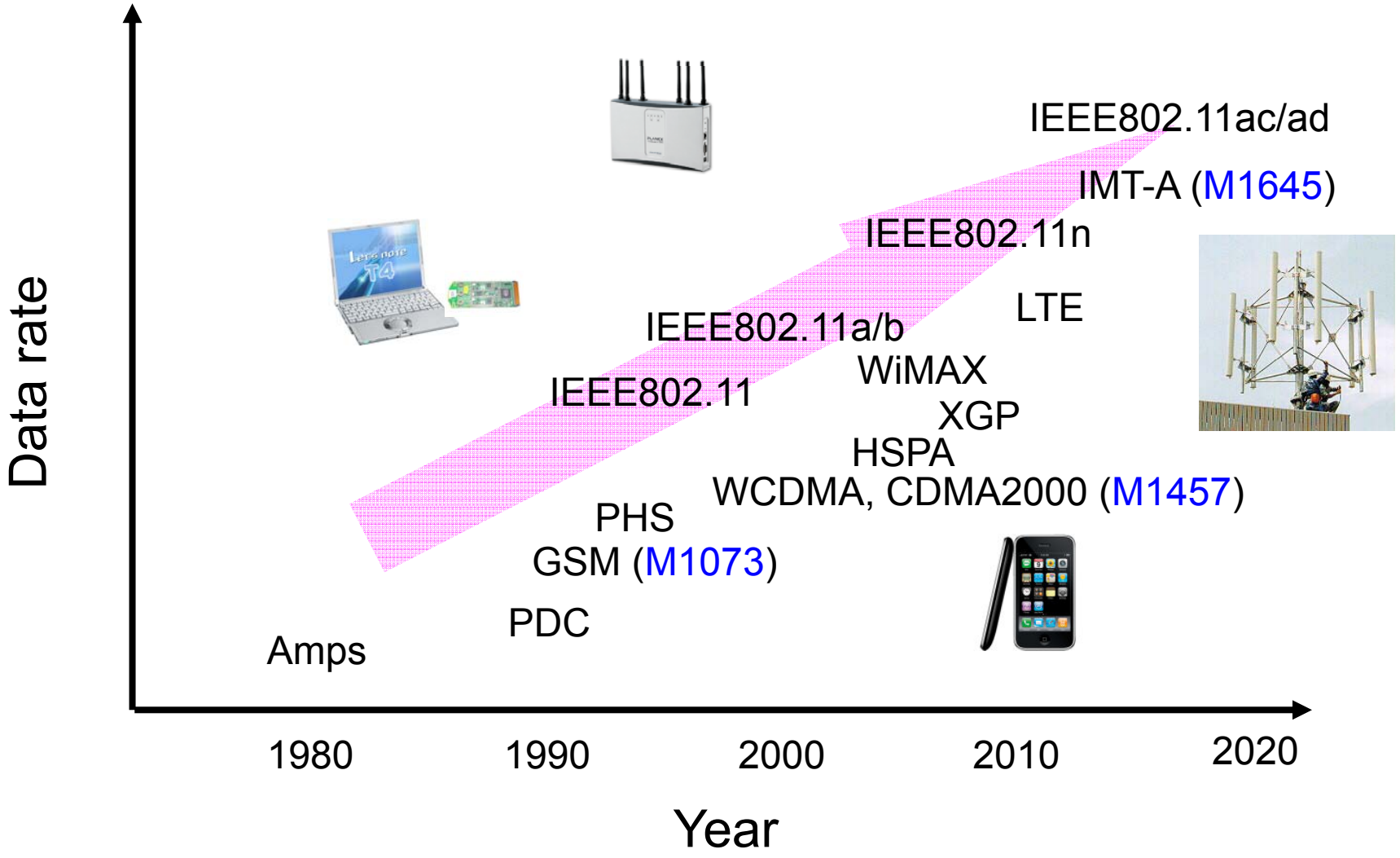
## Aim of today

Overview trend of deployment of MIMO technologies
in world wide wireless standards

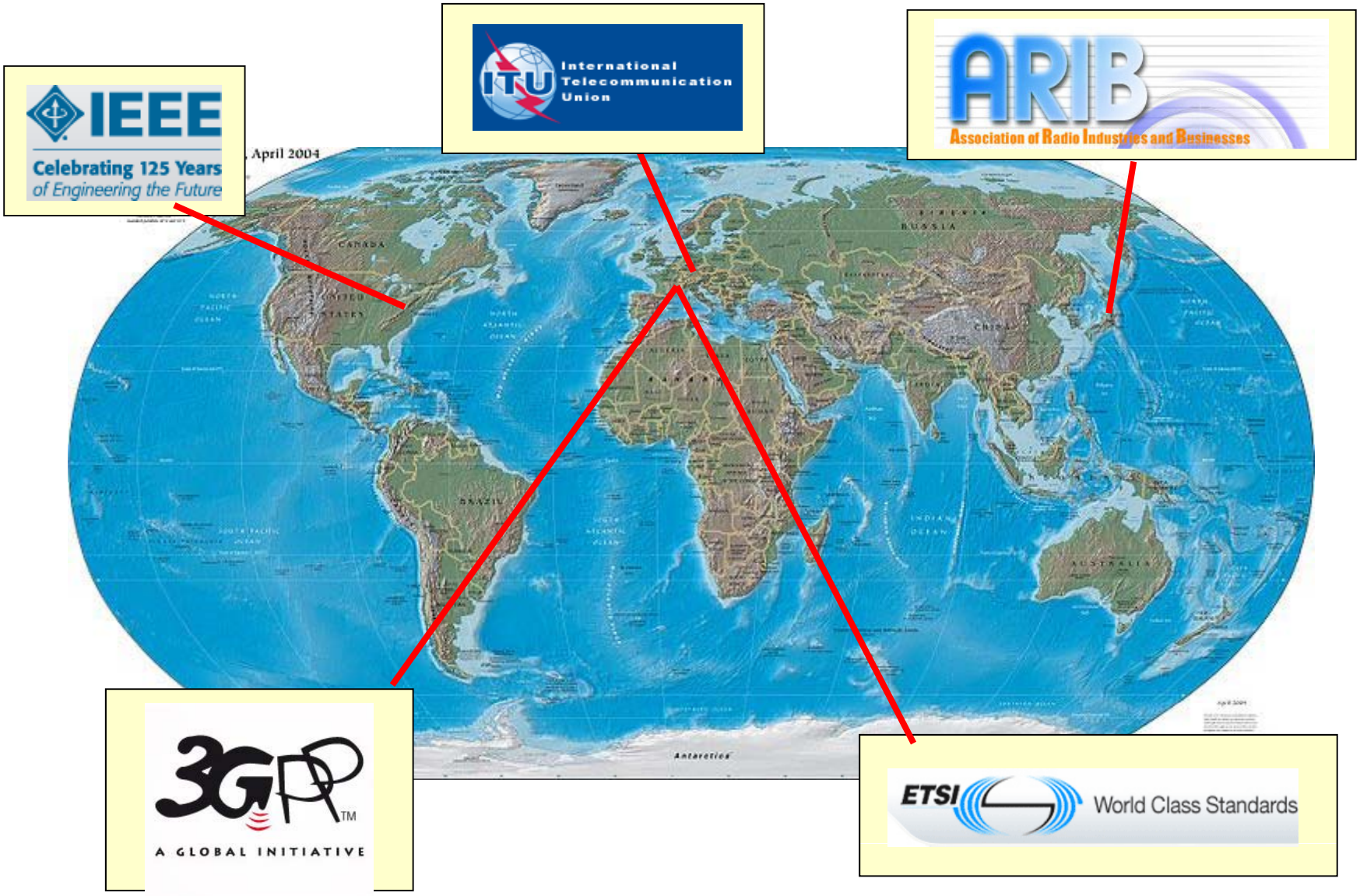
## Contents

- Standardization in the world
- IEEE802.11n wireless LAN
- IEEE802.16e wireless MAN
- 3GPP-LTE (E-UTRA)

# Evolution of Wireless Systems



# Standardization in the World



# IEEE802.11 Wireless LAN

## Indoor wireless local area network for ISM band

| | **IEEE802.11a** | **IEEE802.11b** | **IEEE802.11g** | **IEEE802.11n** |
|---|---|---|---|---|
| Year of approval | 1999 | 1999 | 2003 | 2009 |
| RF band | 5GHz | 2.4GHz | 2.4GHz | 2.4 & 5GHz |
| Channel bandwidth | 20MHz | 20MHz | 20MHz | 20/40MHz |
| Modulation | OFDM | DSSS, CCK | OFDM, CCK | OFDM, CCK |
| Max data rate | 54Mbps | 11Mbps | 54Mbps | 600Mbps |
| MAC | CSMA/CA | CSMA/CA | CSMA/CA | CSMA/CA |

# Features of IEEE802.11n

## IEEE802.11n (Wireless LAN High Throughput)

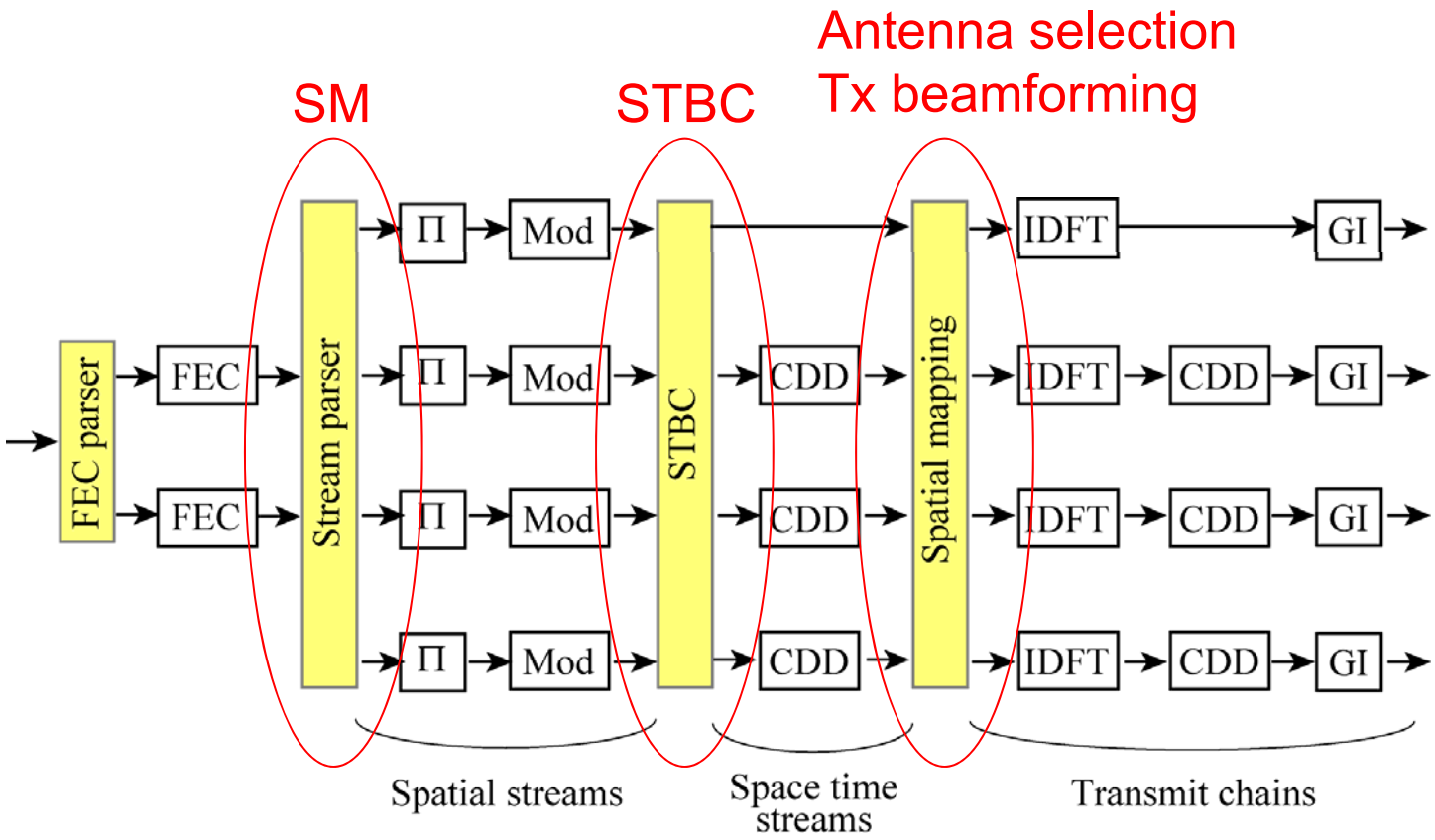
- Objective: Backward compatibility with 802.11a/b/g
  More than 100Mbps throughput at MAC-SAP

- History: Sep. 2004 Voting start (TGnSync, WWiSE, Qualcomm, MITMOT)
  Oct. 2005 TGnSync, WWiSE face off → EWC pre-n
  Jan. 2006 Draft approved
  Aug. 2009 Standard established

- Feature: MIMO spatial multiplexing (2x to 4x)
  MIMO scheme (SM, STBC, Transmit beamforming)
  Implicit/explicit feedback beamforming
  Extended bandwidth (20MHz, 40MHz)
  LDPC (parallel encoder)
  Flexible guard band

# MIMO Architecture for 11n

- High data rate owing to 4-stream Spatial Multiplexing (SM)
- High reliability owing to Space Time Block Coding (STBC)
- Tx Antenna selection and Tx beamforming based on channel (CSI) feedback



# Ongoing Standard of IEEE802.11 W-LAN

## Very High Throughput WLAN

| | **IEEE802.11ac** | **IEEE802.11ad** |
|---|---|---|
| Year to be completed | ~2012 | |
| RF band | < 6GHz | 60GHz < |
| Channel bandwidth | 20, 40, 80, 160 MHz | |
| Modulation | OFDM | |
| Max data rate | 1.5Gbps | |
| MAC | CSMA/CA | |

- Feature:

✓ MIMO scheme :
Single user MIMO
STBC
Multi user MIMO
(Downlink, Uplink)

✓ Implicit/Explicit feedback beamforming

✓ Extended bandwidth (20, 40, 80, 160MHz)

✓ LDPC

# IEEE802.16 Wireless MAN

## Outdoor (fixed) wireless metropolitan area network

| | IEEE802.16 | IEEE802.16-2004 | IEEE802.16e-2005 |
|---|---|---|---|
| Year of approval | 2001 | 2004 June | 2005 Dec |
| RF band | 10 – 66GHz | 2 – 11GHz | 2 – 6GHz (mobile) |
| Channel bandwidth | 20, 25, 28MHz | 1.75 – 15MHz | 5, 7, 8.75, 10, 20MHz |
| Application | Fixed LOS | Fixed NLOS | Mobile NLOS |
| Multiplexing | TDM/TDMA | TDM/TDMA, OFDMA | TDM/TDMA, OFDMA |
| Duplexing | TDD, FDD | TDD, FDD | TDD, FDD |
| Modulation | Single carrier | 256, 2048 OFDM | 128 – 2048 OFDM |
| Max data rate | 134.4Mbps | 75Mbps | 75Mbps |
| MAC architecture | P2MP, mesh | P2MP, mesh | P2MP, mesh |

# Features of IEEE802.16e

## IEEE802.16e (Wireless Metropolitan Area Network)

- Objective: WiMAX (IEEE802.16-2004) with mobility

- History: Dec. 2002 TGe start
  Dec. 2005 Standard established
  June 2006 KT WiBro service start
  Nov. 2006 Profile Release 1 from WiMAX forum
  Jul. 2009 UQ WiMAX service start (Japan)

- Feature: MIMO spatial multiplexing (2x)
  MIMO scheme (SM, STBC, Transmit beamforming)
  Tx precoding based on matrix codebook
  Scalable bandwidth (1, 2, 5, 10, 20 MHz)
  Adaptive resource control based on OFDMA
  Adaptive modulation coding & hybrid ARQ

# 3GPP Universal Mobile Telephone

International standard of cellular wireless network

| | **Release 99 (WCDMA)** | **Release 5/6 (HSPA)** | **Releas 8 LTE (E-UTRA)** |
|---|---|---|---|
| Year of approval | 1999 Dec. | 2002 June/2004 Dec. | 2008 Dec. |
| RF band | 2GHz | 0.9, 2GHz | 0.9, 2GHz |
| Channel bandwidth | 5MHz | 5MHz | 1.25 – 20MHz |
| Multiplexing | TDM/CDMA | TDM/CDMA | OFDMA |
| Duplexing | TDD, FDD | TDD, FDD | TDD, FDD |
| Modulation | QPSK | AMC | AMC |
| Max data rate | 2Mbps | 14.4Mbps | 100Mbps |
| Main feature | Rake<br>Power control | Multi-code<br>MIMO | Next slide |

# Features of 3GPP-LTE (E-UTRA)

## 3GPP Long Term Evolution (Evolved-UTRA)

- Objective: Long term evolution of 3GPP-HSPA
  More than 100Mbps throughput in downlink

- History: Dec. 2004 Evolved UTRA&UTRAN SI set up
  Dec. 2005 3GPP-RAN1 specification established
  June 2006 Evolved UTRA&UTRAN WI set up
  Dec. 2008 Standard established (3GPP, Release 8)

- Feature: MIMO spatial multiplexing (2x)
  MIMO scheme (SM, STBC, Transmit beamforming)
  Downloadable precoding codebook
  Multi-user MIMO (MU-MIMO)
  Adaptive resource control based on OFDMA
  ALL IP backbone network (AIPN)

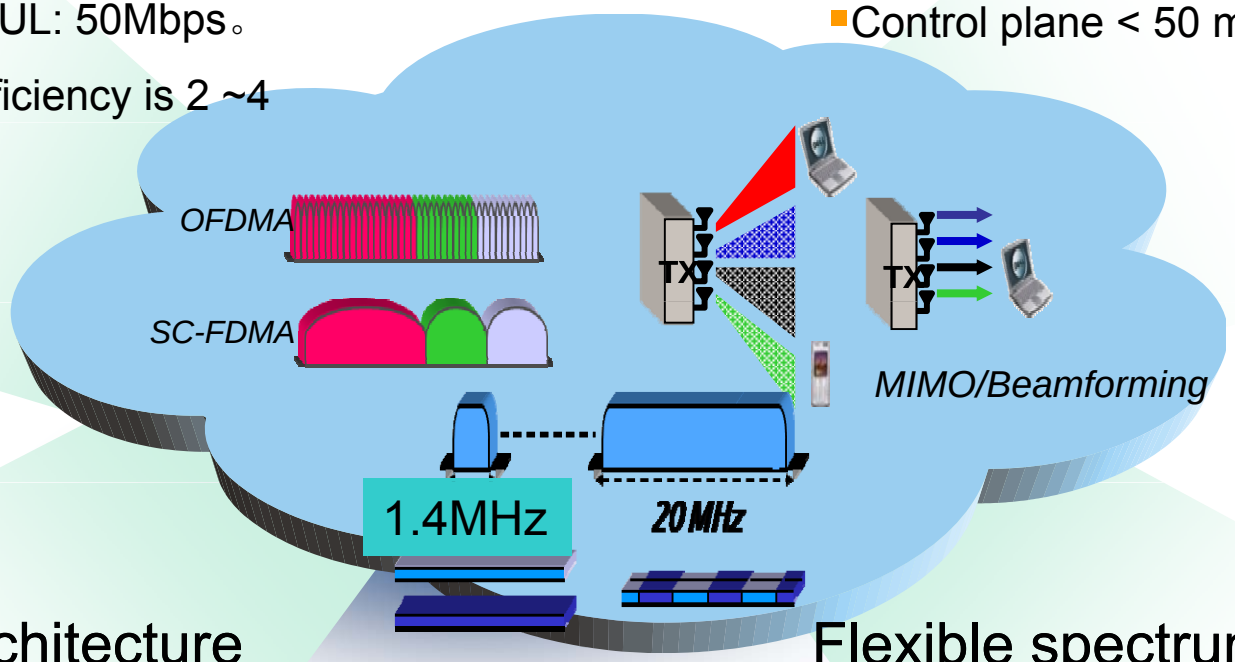
# Concept of LTE

## High Peak data rate and spectrum efficiency

- DL：100Mbps，UL: 50Mbps。
- The spectrum efficiency is 2 ~4 times of HSPA

## Low latency

- User plane < 10 ms
- Control plane < 50 ms




## Flat RAN architecture

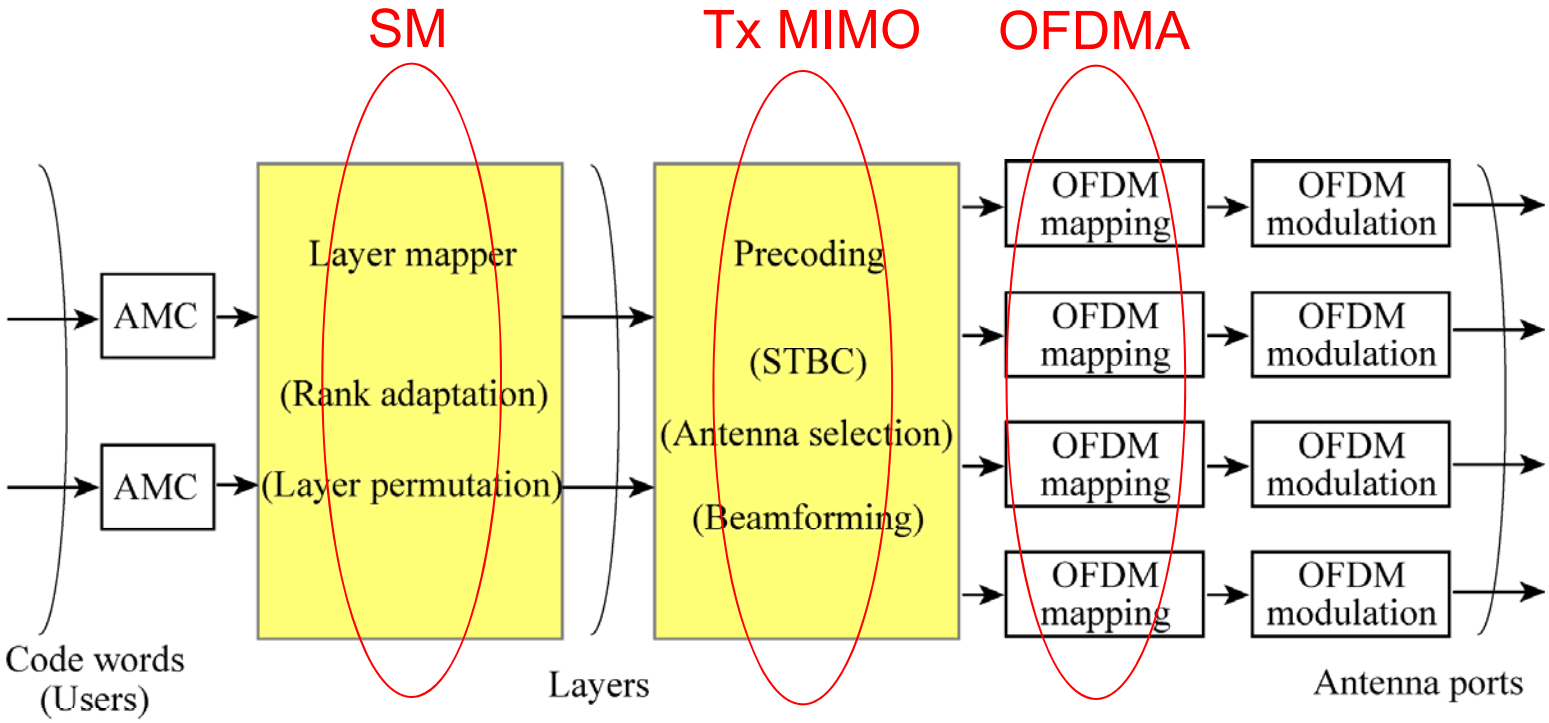

**LTE/SAE**

## Flexible spectrum

- 1.4MHz~20MHz
- support FDD&TDD

# MIMO Architecture for 16e & LTE

- MIMO stream control based on rank adaptation & permutation
- MIMO Tx precoding based on matrix codebook
- Multi-user access & scheduling based on OFDMA + SDMA



# LTE Rel. 8 & 9 Algorithms (1 of 6)

1. Transmit diversity
   a) Two antenna ports
      - Alamouti scheme in the frequency domain (Space-Frequency Block Coding or SFBC)

$$\mathbf{X}_n = \begin{bmatrix} s_{n,1} & s_{n,2} \\ s_{n,2}^* & -s_{n,1}^* \end{bmatrix} \qquad r = \frac{Q}{L} = \frac{2}{2} = 1$$

   b) Four antenna ports
      - SFBC + Frequency Switched Transmit Diversity (SFBC+FSTD)

$$\mathbf{X}_n = \begin{bmatrix} s_{n,1} & s_{n,2} & 0 & 0 \\ 0 & 0 & s_{n,3} & s_{n,4} \\ s_{n,2}^* & -s_{n,1}^* & 0 & 0 \\ 0 & 0 & s_{n,4}^* & -s_{n,3}^* \end{bmatrix} \qquad r = \frac{Q}{L} = \frac{4}{4} = 1$$

# LTE Rel. 8 & 9 Algorithms (2 of 6)

2. Spatial Multiplexing

– Transmitted vector:

$$\mathbf{x}_k = \mathbf{W}_k \mathbf{s}_k$$

a) Open-loop spatial multiplexing:

$$\mathbf{W}_k = \mathbf{I}$$

b) Closed-loop spatial multiplexing for two antenna ports

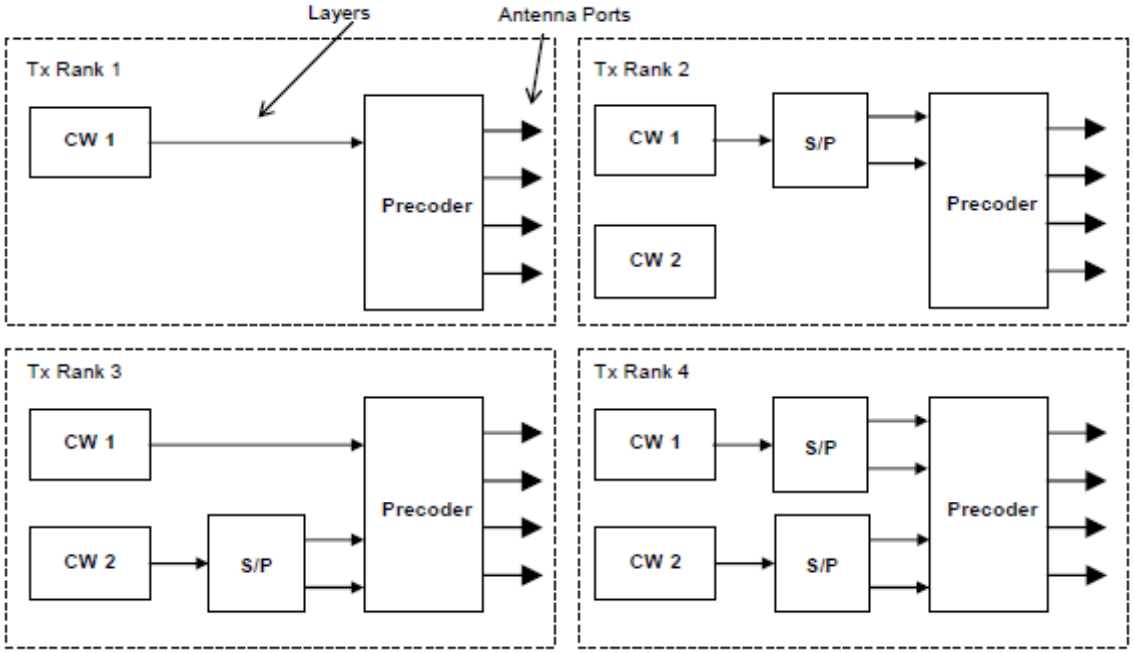
| Tx Rank | Precoder matrix | | | |
|---|---|---|---|---|
| 1 | $\begin{bmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{bmatrix}$ | $\begin{bmatrix} 1/\sqrt{2} \\ -1/\sqrt{2} \end{bmatrix}$ | $\begin{bmatrix} 1/\sqrt{2} \\ j/\sqrt{2} \end{bmatrix}$ | $\begin{bmatrix} 1/\sqrt{2} \\ -j/\sqrt{2} \end{bmatrix}$ |
| 2 | $\begin{bmatrix} 1/\sqrt{2} & 0 \\ 0 & 1/\sqrt{2} \end{bmatrix}$ | $\begin{bmatrix} 1/2 & 1/2 \\ 1/2 & -1/2 \end{bmatrix}$ | $\begin{bmatrix} 1/2 & 1/2 \\ j/2 & -j/2 \end{bmatrix}$ | |

# LTE Rel. 8 & 9 Algorithms (3 of 6)

## 2. Spatial Multiplexing

### c) Closed-loop spatial multiplexing for four antenna ports

- Maximum transmission rank of 4
- 64 precoders (16 per transmission rank)




Fixed set of codeword to layer mappings

# LTE Rel. 8 & 9 Algorithms (4 of 6)

## 2. Spatial Multiplexing

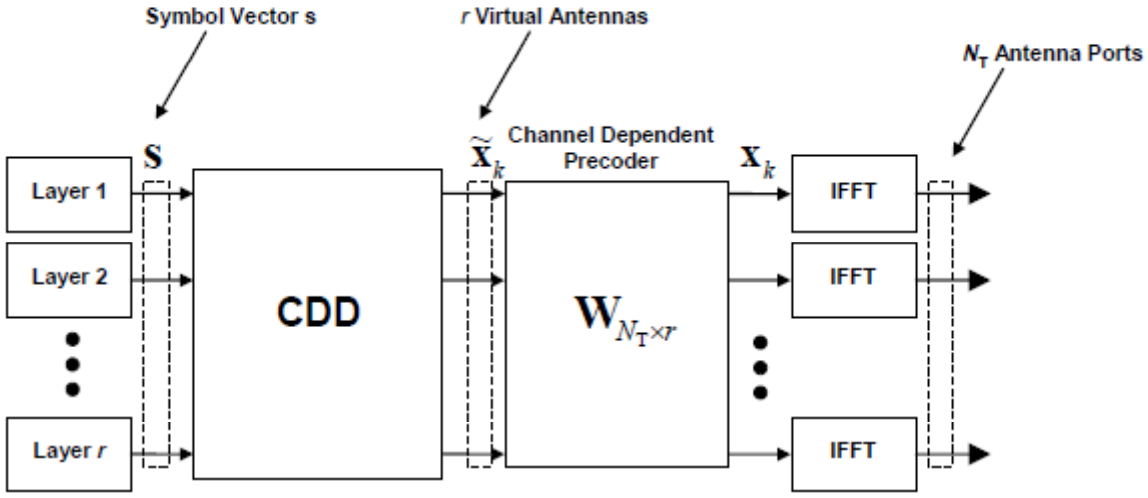
### c) Cyclic Delay Diversity (CDD)

- Channel-independent frequency-selective precoding
- Same signal is transmitted to all antennas except for different delays
- Introduces variation in channel quality over the bandwidth

c1) Single Layer CDD: $\mathbf{w}_m = \begin{bmatrix} 1 & \exp(2j\pi\Delta m/N) & \cdots & \exp(2j\pi\Delta(N_T - 1)m/N) \end{bmatrix}$

- Delay parameter
- $m$ is subcarrier index of DFT size $N$

c2) CDD combined with spatial multiplexing:

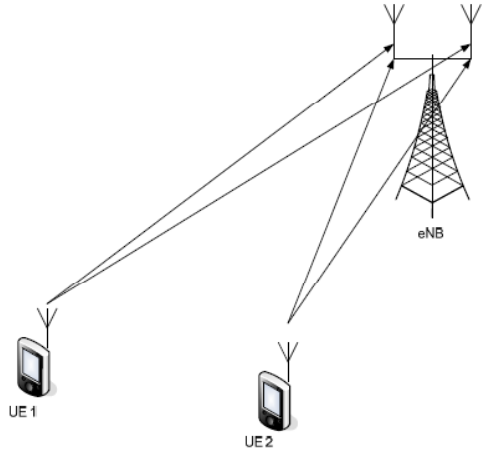


# LTE Rel. 8 & 9 Algorithms (5 of 6)

3. Multiuser MIMO
   - "Space Division Multiple Access" - Simultaneous transmission of several users on the same resource elements
   - Requirement: preferred beams to users are sufficiently well-separated

   a) DL MU-MIMO
      - Each UE is served by single-rank beamforming or single-rank precoding

   b) UL MU-MIMO
      - Release 8 does not support single-user MIMO but the UL can support MU-MIMO using MMSE MIMO decoding



# LTE Rel. 8 & 9 Algorithms (6 of 6)

4. Downlink Beamforming
   - Eigenbeamforming-based beamforming
   - Uses Channel Reciprocity of TDD
   - Uses Sounding Reference Signal and Common Reference Signal for Channel Estimation of Downlink
   - Used for 4 or 8-Tx antennas (6 dB gain over 2Tx is possible under low-speed conditions)

   4a. Single-Layer Dedicated Beamforming

   4b. Dual-Layer Dedicated Beamforming (Release 9 only)

# Comparison of IEEE802.16e & 3GPP-LTE

| | **Mobile WiMAX (IEEE802.16e-2005)** | **3GPP-LTE (E-UTRA)** |
|---|---|---|
| Core network | All-IP network | E-UTRA CN with IMS |
| Access technology | OFDMA(DL/UL) | OFDMA(DL), SC-FDMA(UL) |
| Bit rate/site | 75Mbps(DL MIMO 2x2), 25Mbps(UL) | 100Mbps(DL MIMO 2x2), 50Mbps(UL) |
| Channel bandwidth | 5, 7, 8.75, 10, 20MHz | 1.25 – 20MHz |
| Spectral efficiency | 3.75[bits/s/Hz] | 5[bits/s/Hz] |
| Mobility | 120km/h (hard handover) | 250km/h (hard handover) |
| Legacy | IEEE802.16a through 16d | GSM/GPRS/UMTS/HSPA |
| MIMO config. | 2x2 (DL), 1x2 (UL) | 2x2 (DL/UL), MU-MIMO |
| MIMO schemes | SM, STBC, precoding | SM, STBC, precoding |
| Schedule forecast | 2005 (standard complete)<br>2009 (initial deployment) | 2008 (standard complete)<br>2010 (initial deployment) |

# Requirement of IMT-Advanced

## Peak data rate and peak spectral efficiency

| | | 802.16m | LTE-Advanced | IMT-Advanced |
|---|---|---|---|---|
| **Peak data rate** | **DL** | **-** | **1 Gbps** | **1 Gbps** |
| | **UL** | **-** | **500 Mbps** | |
| **Peak spectral efficiency [bps/Hz]** | **DL** | **15** | **30** | **15** |
| | **UL** | **6.75** | **15** | **6.75** |

• These values were defined assuming an antenna configuration of downlink 4x4, uplink 2x4

# Requirement of IMT-Advanced

## Cell spectral efficiency and cell edge user spectral efficiency

| | | Antenna configuration | 802.16m(*1) | LTE-Advanced (*2) | IMT-Advanced (*3) |
|---|---|---|---|---|---|
| Cell spectral efficiency [bps/Hz/cell] | DL | 2-by-2 | 2.6 | 2.4 | – |
| | | 4-by-2 | – | 2.6 | 2.2 |
| | | 4-by-4 | – | 3.7 | – |
| | UL | 1-by-2 | 1.3 | 1.2 | – |
| | | 2-by-4 | – | 2.0 | 1.4 |
| Cell edge user spectral efficiency [bps/Hz/cell/user] | DL | 2-by-2 | 0.09 | 0.07 | – |
| | | 4-by-2 | – | 0.09 | 0.06 |
| | | 4-by-4 | – | 0.12 | – |
| | UL | 1-by-2 | 0.05 | 0.04 | – |
| | | 2-by-4 | – | 0.07 | 0.03 |

(*1)IEEE L802.16-09/0114r4, (*2)3GPP TR36.913 (Case 1), (*3)ITU-R M.2135 (Base coverage urban)

# Features of IEEE802.16m

## IEEE802.16m (Wireless Metropolitan Area Network)

Objective: provide performance improvements of 802.16e to fulfill requirements of IMT-A

| | **IEEE802.16m** |
|---|---|
| Year of approval | 2011 (scheduled) |
| RF band | <6GHz |
| Channel bandwidth | 5 - 20MHz |
| Application | Mobile NLOS |
| Multiplexing | OFDMA |
| Duplexing | TDD, FDD |
| Modulation | Scalable OFDM |
| Max data rate | 300Mbps |
| MAC architecture | P2MP, mesh |

- Timeline: Apr. 2007 TGm starts
  Jul. 2009 First draft
  Sep. 2009 Proposal to IMT-A
  Mar. 2011 Standard established

- Feature: Backward compatibility with WMAN-OFDMA
  Multiple antenna schemes (SM, diversity, multi-user MIMO)
  Support multi-hop relay, femto cell and self organization
  Connection-oriented MAC
  Coexistence with other radio technologies

# Features of LTE-Advanced

## 3GPP wireless interface to meet requirement of IMT-Advanced

• Objective : Evolution from Rel.8 to fulfill requirement of IMT-Advanced

| | LTE-Advanced |
|---|---|
| Year of approval | 2011 (Release 10) |
| RF band | 700/900MHz, 2GHz, 3.5GHz |
| Channel bandwidth | Up to 100MHz |
| Multiplexing | SC-FDMA, OFDMA |
| Duplexing | TDD, FDD |
| Modulation | AMC |
| Peak data rates | 1Gbps |

• Timeline

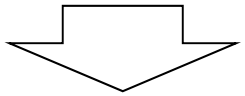
- Mar. 2008 LTE-A (Release 10) SI set up
- Dec. 2009 LTE-A (Release 10) WI set up
- Mar. 2011 RAN1 specification established

• Feature

- Backward compatibility with LTE
- Support wider bandwidth
  Carrier/spectrum aggregation up to 100MHz
- Advanced MIMO techniques
  Spatial multiplexing (DL: 8 layers, UL: 4 layers)
  Enhanced MU-MIMO
-Coordinated multipoint transmission and reception (CoMP)
- Relaying

# Summary

- Standardization of MIMO systems
  - IEEE802.11n wireless LAN in 2009
    Pre-n started 2006 and 11n started in 2010
  - IEEE802.16e (M-WiMAX) wireless MAN in 2005
    WiMAX service started in 2009 at 2.5GHz band
  - 3GPP-LTE (E-UTRA) wireless cellular network
    LTE service (Xi) started in Dec. 2010 at 800MHz band



For your future work

Enjoy standardization in IMT-Advanced & others

# Final Examination

- Date:  July 12 (Tue.),  9:00 – 10:30
- Place:  S323 lecture room
- Test procedure
  - Blind test
  - Calculator is allowed
  - Contents
    OFDM, Array signal processing, MIMO channel capacity, MIMO propagation, MIMO receiver, MIMO transmitter, Adaptive MIMO, Multi-user MIMO