Introduction to 5G

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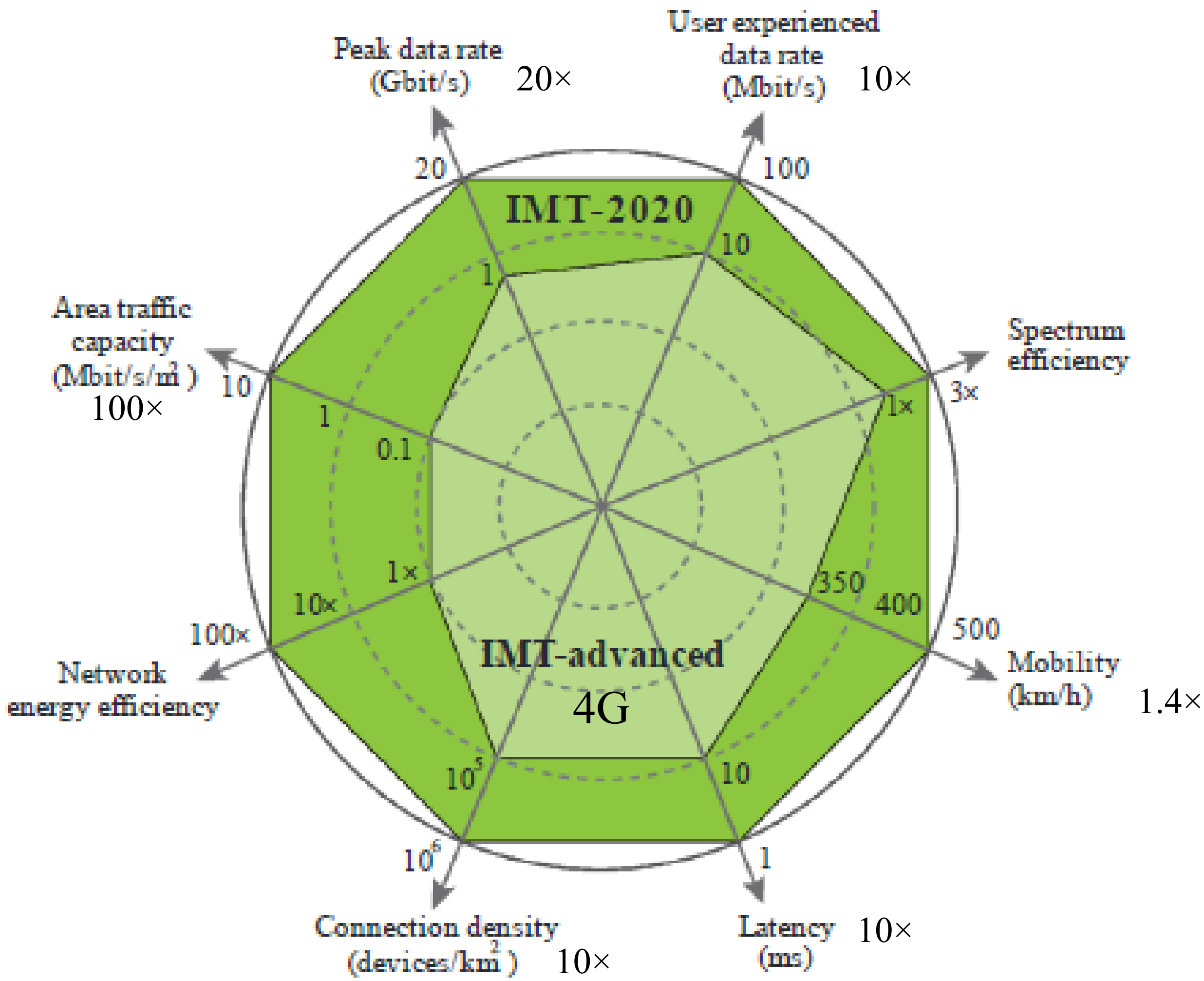
Slides and Audio/Video recordings of this class lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-16/

1. What: 5G Definition
2. How:
    1. New Radio Multiplexing Technologies
    2. New Efficient Spectrum Usage Techniques
    3. New Energy Saving Mechanisms
    4. CapEx/OpEx Reduction Techniques
    5. New Spectrum
    6. Application Specific Improvements

Note: This is the 4th module in a series of lectures on 2G/3G, LTE, LTE-Advanced, and 5G

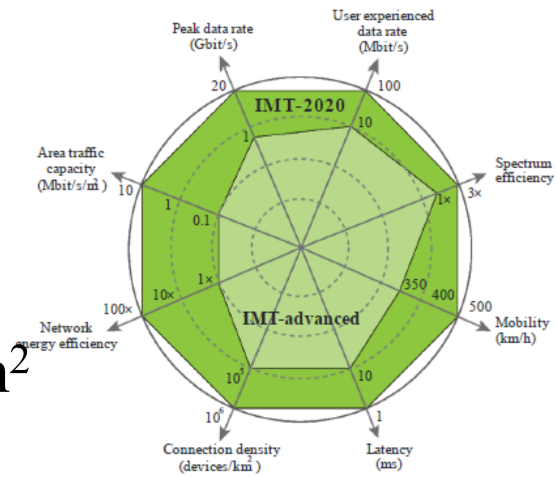
5G Definition



Ref: ITU-R Recommendation M.2083-0, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," Sep. 2015, 21 pp., https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

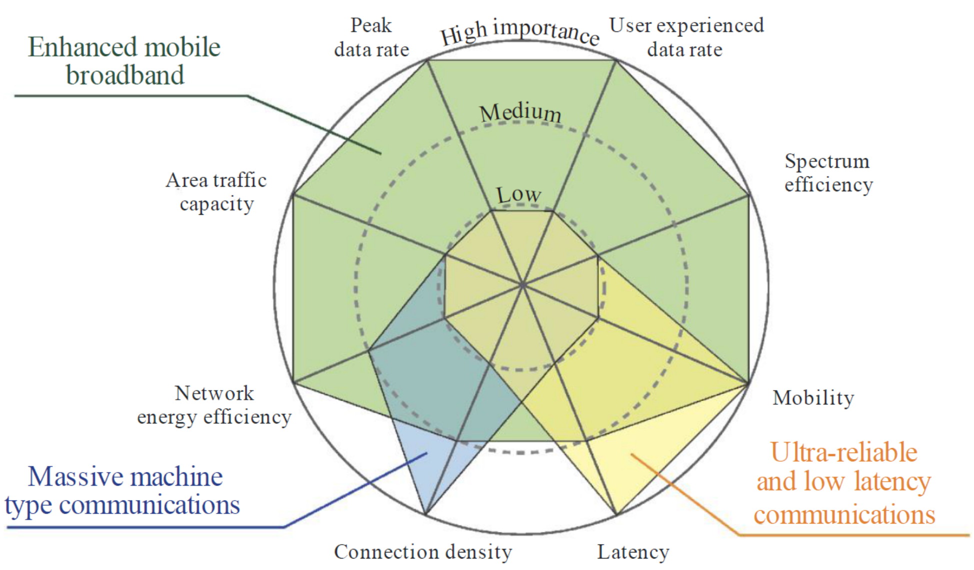
5G Definition (Cont)

1. Peak Data Rate: max rate per user under ideal conditions. 10 Gbps for mobiles, 20 Gbps under certain conditions.
2. User experienced Data Rate: Rate across the coverage area per user. 100 Mbps in urban/suburban areas. 1 Gbps hotspot.
3. Latency: Radio contribution to latency between send and receive
4. Mobility: Max speed at which seamless handover and QoS is guaranteed
5. Connection Density: Devices per km^2
6. Energy Efficiency: Network bits/Joule, User bits/Joule
7. Spectrum Efficiency: Throughput per Hz per cell
8. Area Traffic Capacity: Throughput per m^2



Importance

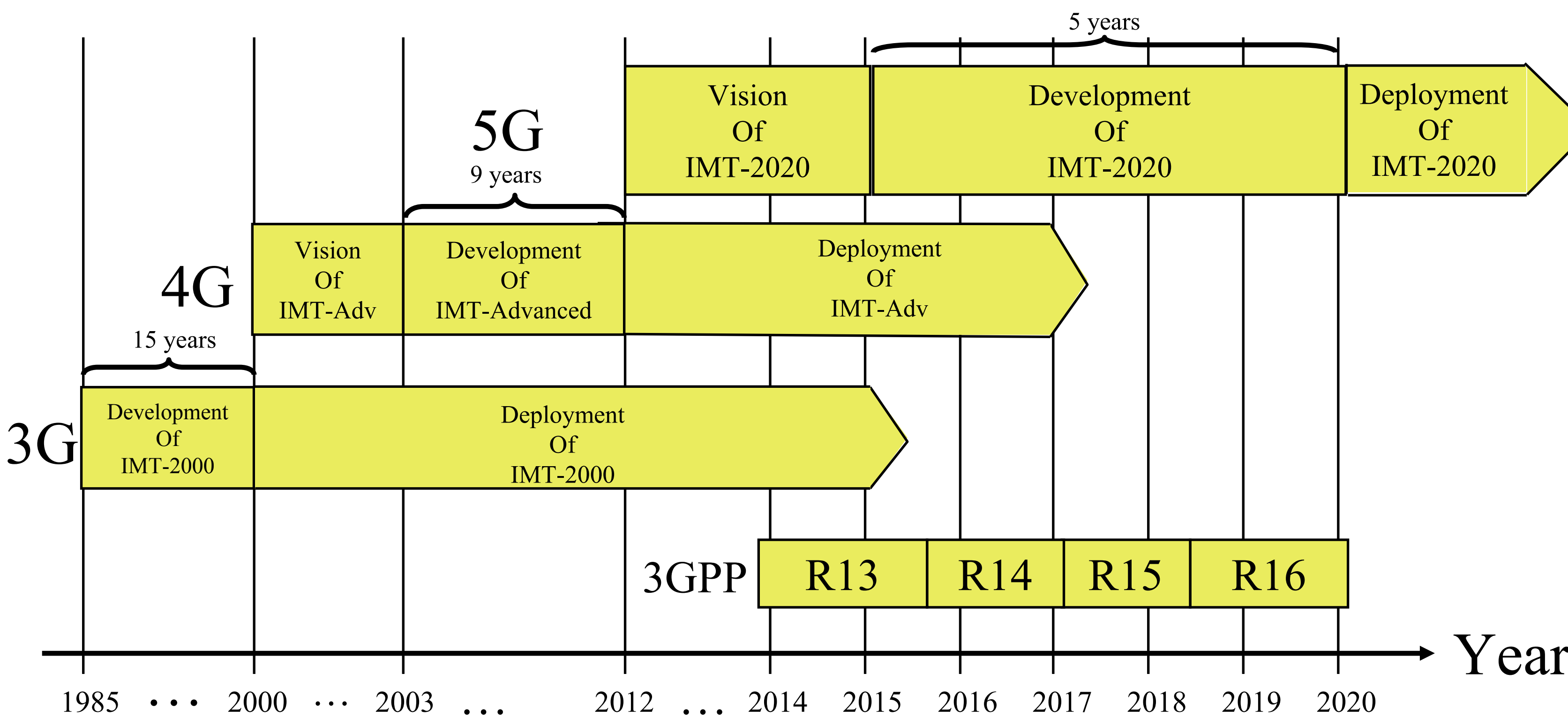
- Three Key Application Areas:
  - Enhanced Mobile Broadband
  - Ultra-Reliable and Low Latency: Real-time, safety
  - Massive Machine Type Communications



Ref: ITU-R Recommendation M.2083-0, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," Sep. 2015, 21 pp., https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

Timeline

- 3G: IMT-2000 started in 1985, first release in 2000
- 4G: IMT-Advanced, vision in 2003, First release in 2012
- 5G: IMT-2020, vision in 2015, first release in 2020



Ref: ITU-R, "Workplan, timeline, process and deliverables for the future development of IMT," 4pp.,

How?

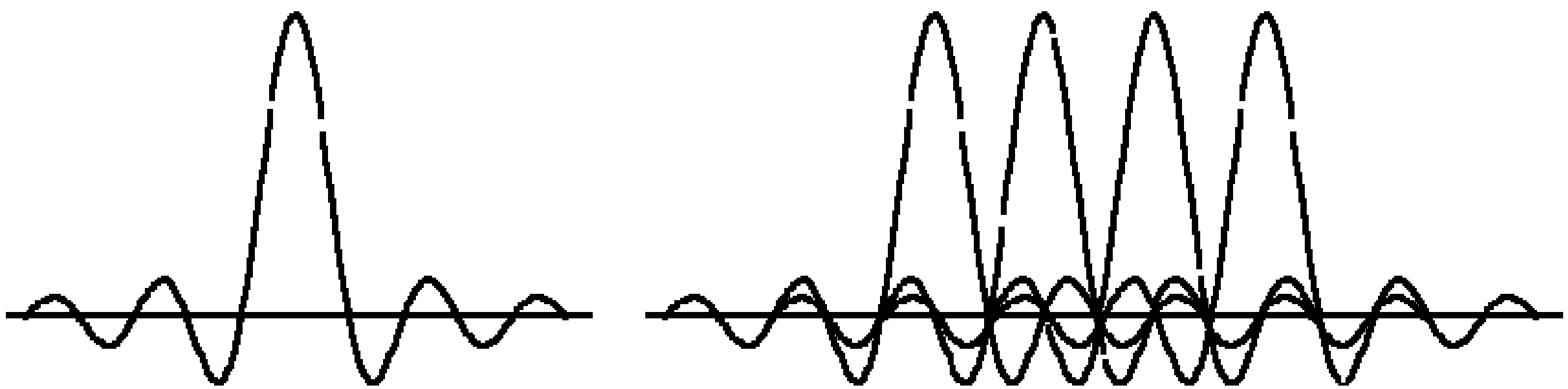
1. New Radio Multiplexing Technologies
2. New Efficient Spectrum Usage Techniques
3. New Energy Saving Mechanisms
4. CapEx/OpEx Reduction Techniques
5. New Spectrum
6. Application Specific Improvements

New Radio Multiplexing Technologies

1. Spectrum Filtered OFDM (f-OFDM)
2. Filtered Bank Multicarrier (FBMC)
3. Non-Orthogonal Multiple Access (NOMA)
4. Pattern Division Multiple Access (PDMA)
5. Low Density Spreading (LDS)
6. Sparse Code Multiple Access (SCMA)
7. Interleave-Division Multiple Access (IDMA)

Problems with OFDM

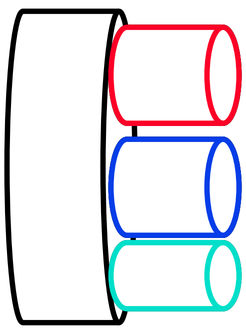
- Spectrum overflow ⇒ Need **guard bands**
- Entire band should use the **same subcarrier** spacing
- Entire time should use the **same symbol size** and cyclic prefix
- All users should strictly **time synchronize** in the uplink

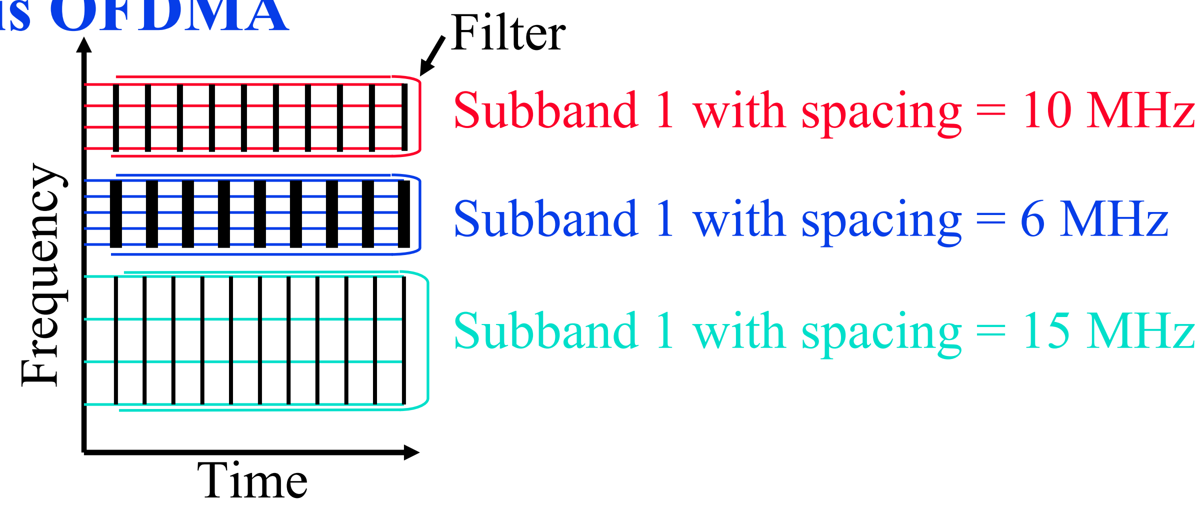


Ref: P. Zhu, "5G Enabling Technologies," PIMRC, Sep 2014, 20 slides, http://www.ieee-pimrc.org/2014/2014-09-03%205G%20Enabling%20Technologies%20PMIRC%20Huawei_Final.pdf

Spectrum Filtered OFDM (f-OFDM)

- Band divided into multiple subbands
- Each subband may use different OFDM parameters optimized for the application: Frequency spacing, cyclic prefix, …
- Each subband spectrum is **filtered** to avoid inter-subband interference ⇒ Spectrum filtered
- Different users (subbands) do not need to be time synchronized ⇒ **Asynchronous OFDMA**

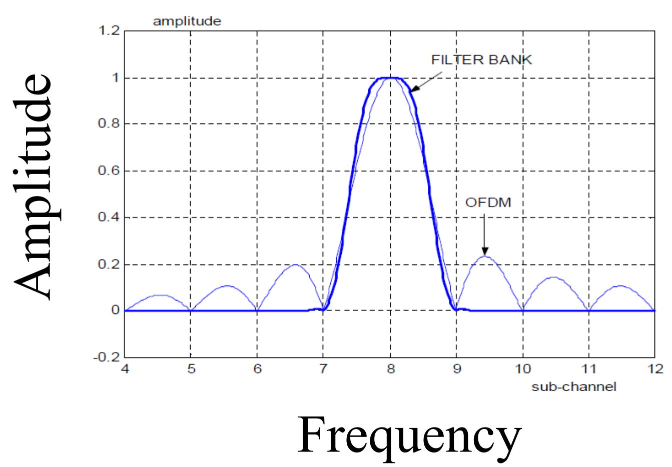


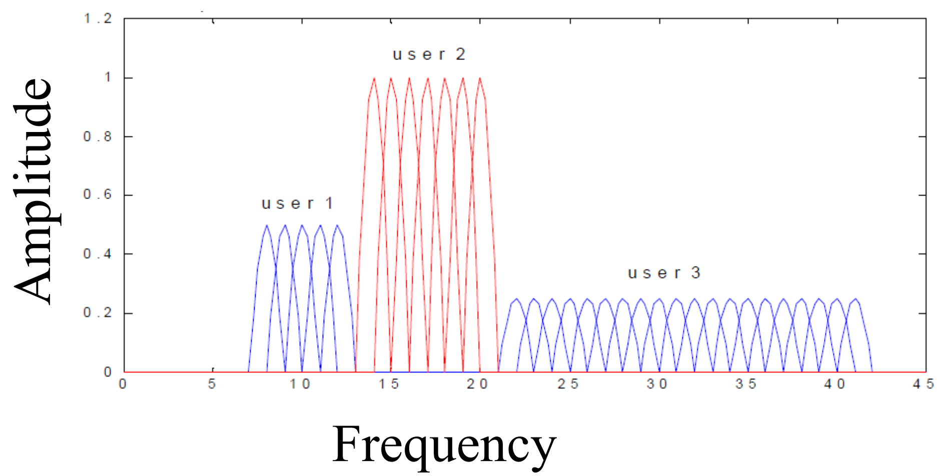


Ref: P. Zhu, "5G Enabling Technologies," PIMRC, Sep 2014, 20 slides, http://www.ieee-pimrc.org/2014/2014-09-03%205G%20Enabling%20Technologies%20PMIRC%20Huawei_Final.pdf

Filtered Bank Multicarrier (FBMC)

- A filter is used to remove the subcarrier overflow
- No side lobes ⇒ No cyclic prefix needed
  ⇒ More bits/Hz
- Different users can have different subbands with different parameters

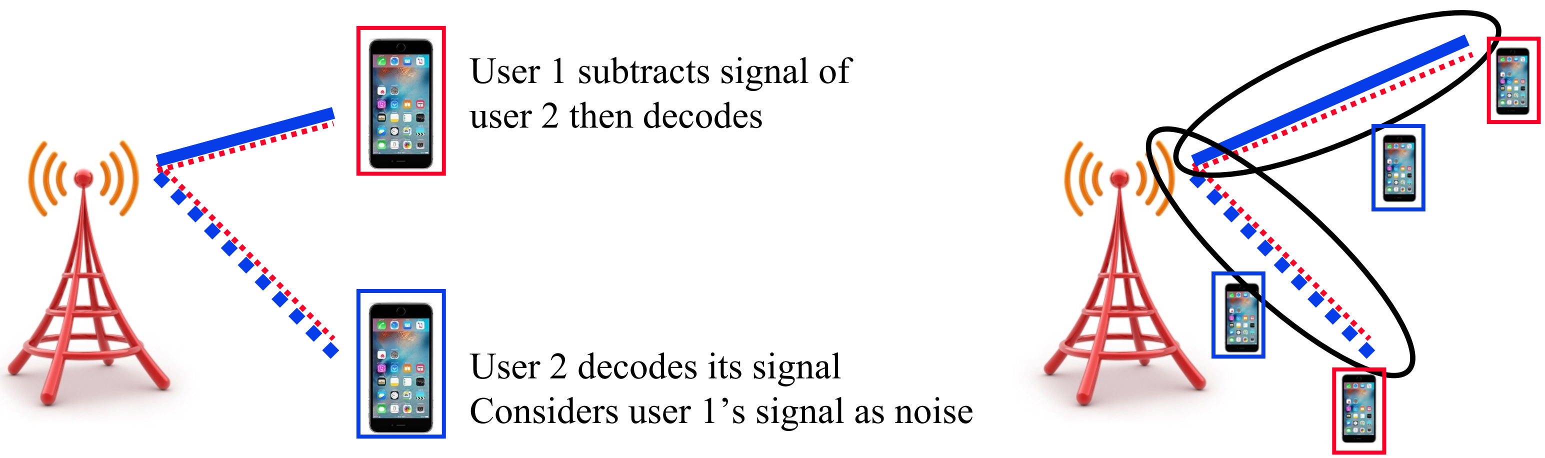




Ref: M. Bellanger, "FBMC physical layer – principle," June 2011, 13 slides,
http://www.cept.org/Documents/se-43/500/SE43(11)Info06_FBMC-physical-layer-principle

Non-Orthogonal Multiple Access (NOMA)

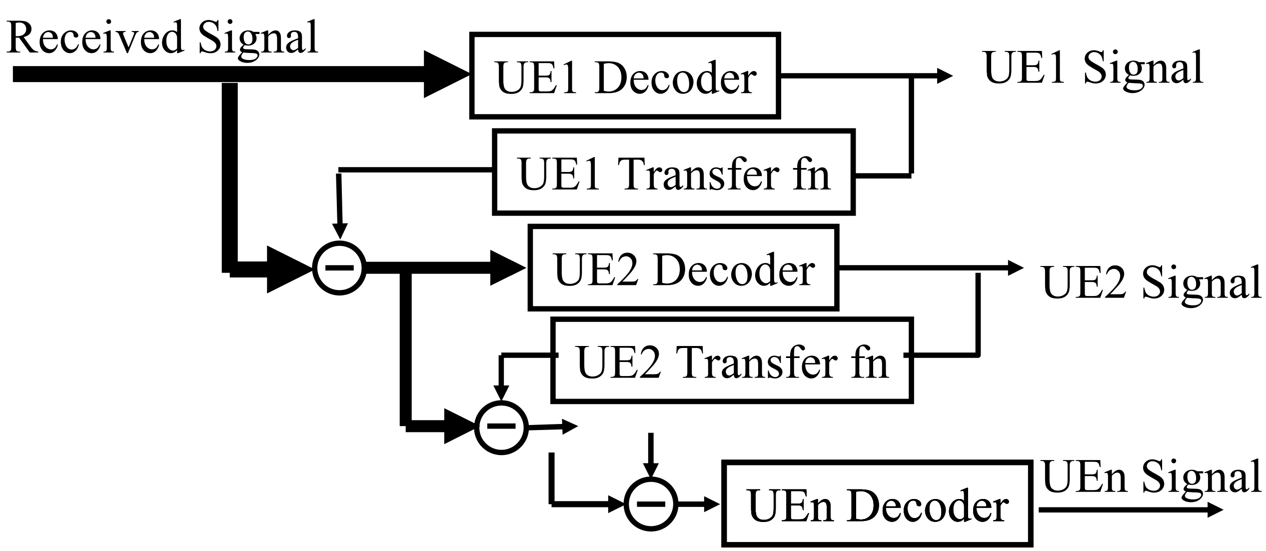
- Users are distinguished by power levels
- Users with poor channel condition get higher power
- Users with higher power decode their signal treating others as noise
- Users with lower power subtract the higher powered signals before decoding
- Can also be used with beamforming and MIMO



Ref: G. Ding, et al, "Application of Non-orthogonal Multiple Access in LTE and 5G Networks," https://pdfs.semanticscholar.org/a404/21a9762db528bfe848166765fee43e740c94.pdf

Pattern Division Multiple Access (PDMA)

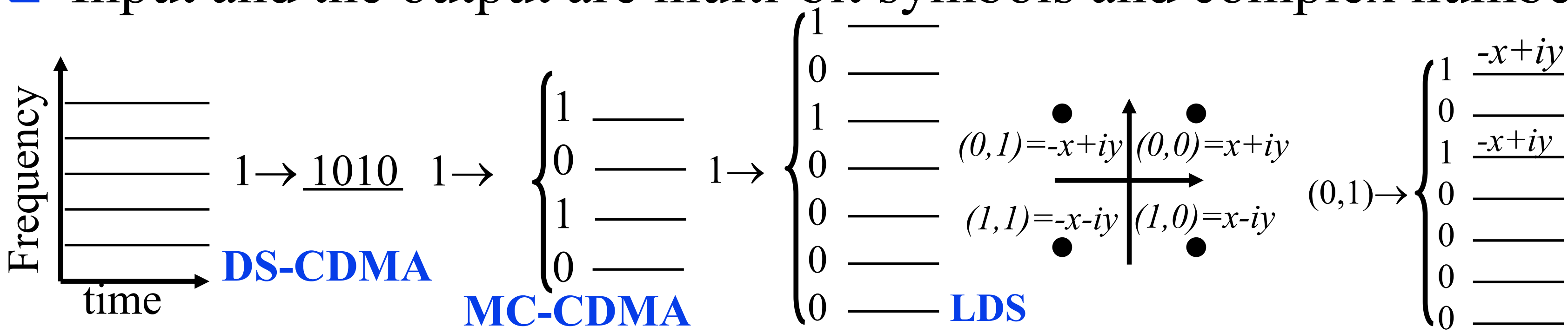
- A variation of NOMA
- The users detect the signal with highest signal, subtract its waveform ⇒ Successive Interference Cancellation (SIC)
- Can increase spectral efficiency by a factor between 1 and 2.



Ref: J. Zeng, et al, "Pattern Division Multiple Access (PDMA) for Cellular Future Radio Access," Intl Conf on Wireless Comm & Signal Proc (WCSP), Oct. 2015, 5 pp., http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=7341229

Low Density Spreading (LDS)

- **Direct Sequence-CDMA**: Symbols are *spread* in time. Multiple users spread over at same time and frequency.
- **Multi-carrier CDMA**: Symbols are *spread* in frequency. Multiple users spread over same subcarriers at same time.
- **LDS**: Multi-carrier CDMA in which symbols are spread over large vectors most of whose elements are zero (sparse).
  - At each subcarriers, the number of interferers is small
  - Codes can even be randomly chosen
- Input and the output are multi-bit symbols and complex numbers.



Ref: M. AL-imari, et al., "Low Density Spreading Multiple Access," J. Inform Tech Software Eng, Vol 2, Issue 4, 2012, http://epubs.surrey.ac.uk/788182/1/Ready%20to%20Upload.pdf

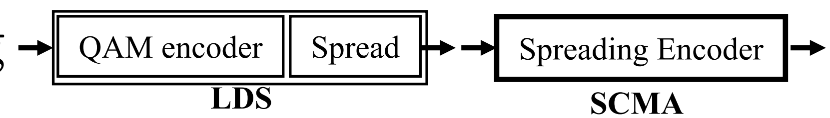
Sparse Code Multiple Access (SCMA)

- In stead of repeating the same symbol on different subcarriers (as in LDS), optimally coded symbols on different subcarriers.
- Symbols are mapped to higher-dimensional complex symbols and then mapped to subcarriers
  - K dimensions are spread over K subcarriers
- Codes are non-orthogonal ⇒ More code books and users can be supported than if limited to orthogonal
- Sparse ⇒ A lot of zeros in the code book ⇒ Easier to decode
  - All codes in one codebook have zeros in the same location
  - Each code book has K dimension of which N are zero. Total ${}^{K}C_{N} = \binom{K}{N}$ codebooks.
- Good for unscheduled random access without polling and grant scheduling ⇒ Good for IoT
- SCMA combines spreading and coding

Ref: P. Zhu, "5G Enabling Technologies," PIMRC, Sep 2014, 20 slides, http://www.ieee-pimrc.org/2014/2014-09-03%205G%20Enabling%20Technologies%20PMIRC%20Huawei_Final.pdf

SCMA Example

- 2-bit symbols to <u>4</u>-dimensional symbols with <u>2</u> zeros: K=4, N=2
- Number of possible mappings $^4C_2 = \binom{4}{2} = 6$ codebooks
- Six users can be supported over 4 subcarriers
- Each codebook has 2 zeros in the same rows for entire codebook.
- Combines spreading and coding



frequency ↑ Subcarriers

	User 1 (00 01 10 11)	User 2 (00 01 10 11)	User 3 (00 01 10 11)	User 4 (00 01 10 11)	User 5 (00 01 10 11)	User 6 (00 01 10 11)
Subcarrier 1	$x_1\ x_3\ x_5\ x_7$	$y_1\ y_3\ y_5\ y_7$	$z_1\ z_3\ z_5\ z_7$	0 0 0 0	0 0 0 0	0 0 0 0
Subcarrier 2	$x_2\ x_4\ x_6\ x_8$	0 0 0 0	0 0 0 0	$u_1\ u_3\ u_5\ u_7$	0 0 0 0	$w_1\ w_3\ w_5\ w_7$
Subcarrier 3	0 0 0 0	$y_2\ y_4\ y_6\ y_8$	0 0 0 0	$u_2\ u_4\ u_6\ u_8$	$v_1\ v_3\ v_5\ v_7$	0 0 0 0
Subcarrier 4	0 0 0 0	0 0 0 0	$z_2\ z_4\ z_6\ z_8$	0 0 0 0	$v_2\ v_4\ v_6\ v_8$	$w_2\ w_4\ w_6\ w_8$

$x_i, y_i, \ldots, w_i$ are complex numbers

Data Bits: 11↓ 10↓ 11↓ 01↓ 00↓ 01↓

$$\begin{bmatrix} x_7 \\ x_8 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} y_5 \\ 0 \\ y_6 \\ 0 \end{bmatrix} + \begin{bmatrix} z_7 \\ 0 \\ 0 \\ z_8 \end{bmatrix} + \begin{bmatrix} 0 \\ u_3 \\ u_4 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ v_1 \\ v_2 \end{bmatrix} + \begin{bmatrix} 0 \\ w_3 \\ 0 \\ w_4 \end{bmatrix} = \begin{bmatrix} x_7+y_7+z_7 \\ x_8+u_3+w_3 \\ y_6+u_4+v_1 \\ z_8+v_2+w_4 \end{bmatrix}$$

Subcarriers

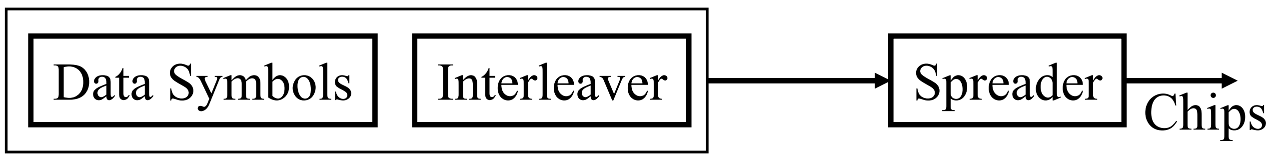
Ref: K. Au, et al, "Uplink Contention Based SCMA for 5G Radio Access," http://arxiv.org/vc/arxiv/papers/1407/1407.5495v1.pdf

Interleave-Division Multiple Access (IDMA)

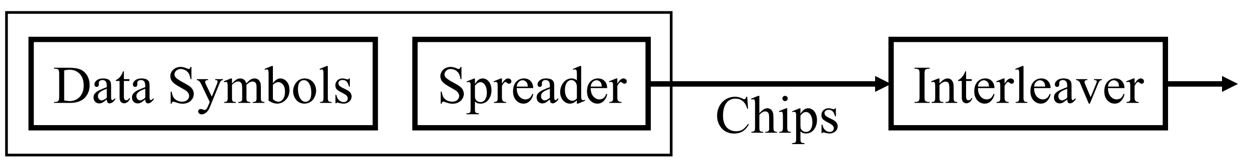
- **Interleaving**: Rearranging symbols according to a specified pattern ⇒ Reduces correlation between successive symbols

  [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, 1]× [2, 4, 3,1]→[1, 3, 2, 0, 5, 7, 6, 4, 9, 1, 0, 8]

- **DS-CDMA**: Symbols are interleaved then spread in to chips



- **IDMA**: Symbols spread and then interleaved.



  - Different users have different interleaving pattern
  - Low-Rate Spreading ~ DS-CDMA without spreading ⇒ High spectral efficiency

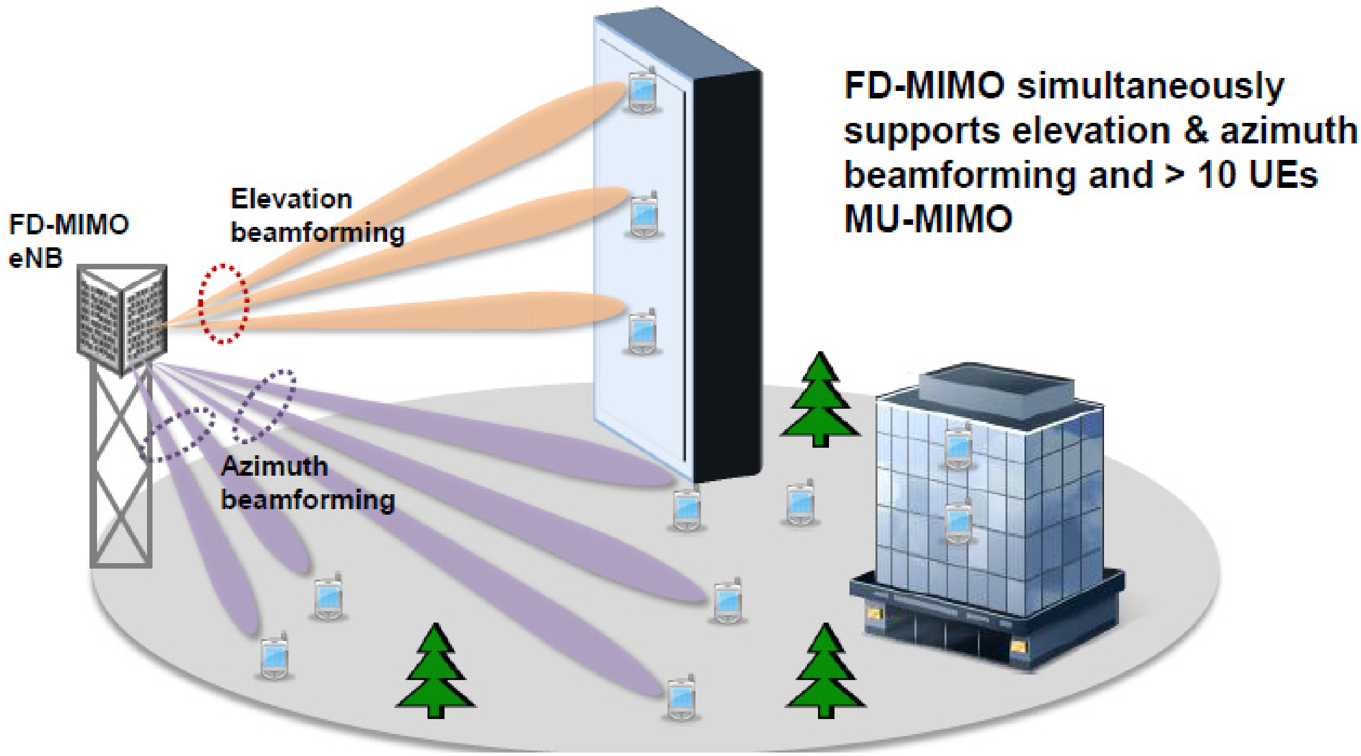
Ref: J. C. Fricke, et al, "An Interleave-Division Multiple Access Based System Proposal for the 4G Uplink," IST Summit, 2005, 5 pp., http://www.agilon.de/Dr__Hendrik_Schoneich/Publications/Fricke_IST_Summit_2005.pdf

New Efficient Spectrum Usage Techniques

1. 3D Beamforming and Massive MIMO
2. FDD-TDD Carrier Integration
3. Distributed Antenna Systems (DAS)
4. Simultaneous Transmission and Reception
5. Dynamic TDD
6. License Assisted Access (LAA)
7. Multimode Base Stations
8. Intelligent Multi-Mode RAT Selection
9. Higher order modulations in small cells

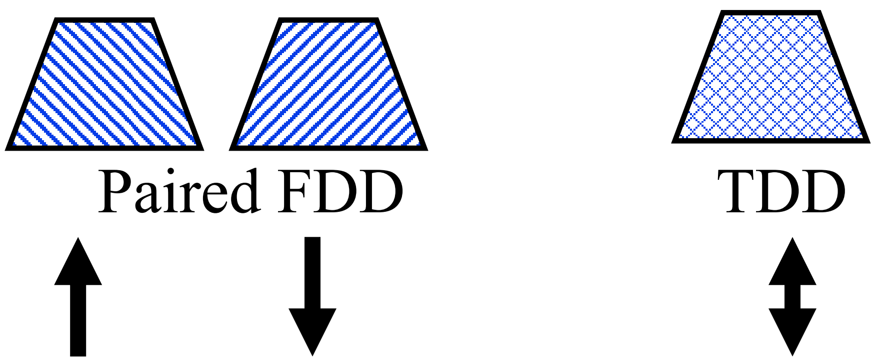
3D Beamforming

- Aka 3D-MIMO or Full-dimension MIMO (**FD-MIMO**)
- Infinite Antennas = **Massive MIMO**



Ref: G. Xu, et al, "Full-Dimension MIMO: Status and Challenges in Design and Implementation," May 2014, http://www.ieee-ctw.org/2014/slides/session3/CTW_2014_Samsung_FD-MIMO.pdf

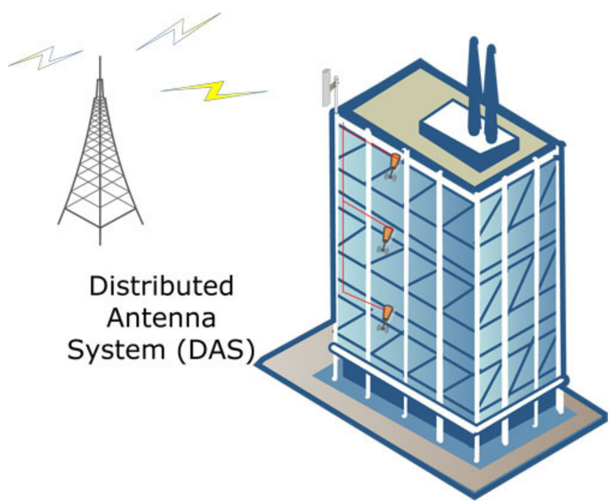
FDD-TDD Carrier Integration



- Can aggregate Down FDD band with TDD in downlink
- Aggregate Up FDD band with TDD in uplink
- Use only FDD in Primary Cell and TDD in Small Cell or vice versa
- Generally FDD bands are lower frequency ⇒ Used for primary
- In future, 32 carriers could be aggregated

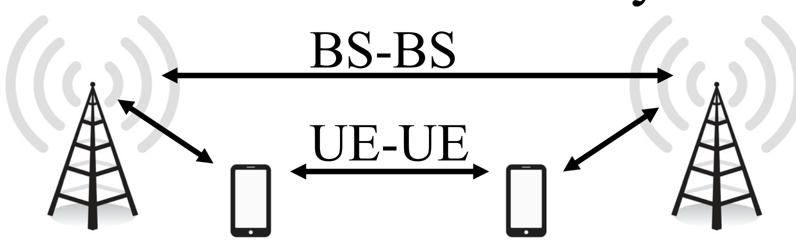
Distributed Antenna Systems (DAS)

- Multiple antennas connected via cable
- Used for indoor coverage
- Need multiple cables for MIMO
- Some times the RF signal is converted to digital and transmitted over fiber optic cables and converted back to RF
  $\Rightarrow$ Active DAS



Simultaneous Transmission and Reception

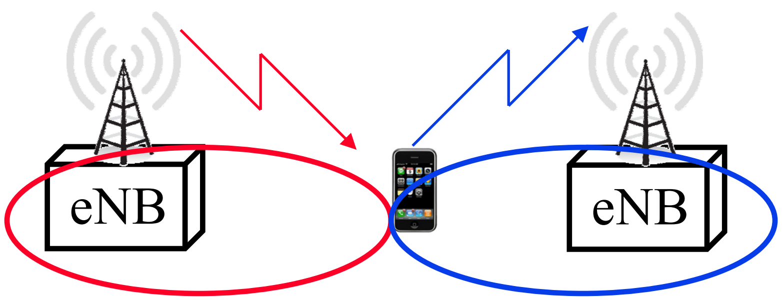
- Also known as "**Full Duplex**" on the same frequency
  ⇒ Doubles the throughput, reduces end-to-end latency, allows transmitters to monitor the channel
- Difficult because transmitted signal too strong and interferes with reception ⇒ FDD (Large gap between transmit and receive frequencies) or TDD (Half-Duplex)
- Solution: **Self-Interference cancellation (SIC)** in analog and digital domain
- Similar techniques can be used to overcome BS-BS or UE-UE interference
- SIC can also be used in Multi-radio systems (WiFi and Bluetooth)



Ref: W. Afifi and M. Krunz, "Adaptive Transmission-Reception-Sensing Strategy for Cognitive Radios with Full-duplex Capabilities," April 2010, 12 pp., http://www2.engr.arizona.edu/~wessamafifi/DySPAN14.pdf

Dynamic TDD

- Time Division Duplexing (TDD) allows varying uplink to downlink ratio
- All cells in an area must synchronize their UL/DL subframes pattern, otherwise mobile's transmission get interference from neighboring BS
- LTE allows 7 variations of UL/DL subframe patterns. S=Switchover time from D to U



TDD Conf	TTI index									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Ref: V. Pauli, Y. Li, E. Seidel, "Dynamic TDD for LTE-A and 5G," Nomor Research GmbH, Sep 2015, 8 pp., http://nashville.dyndns.org:823/YourFreeLibrary/_lte/LTE%20advanced/WhitePaperNomor_LTE-A_5G-eIMTA_2015-09.pdf

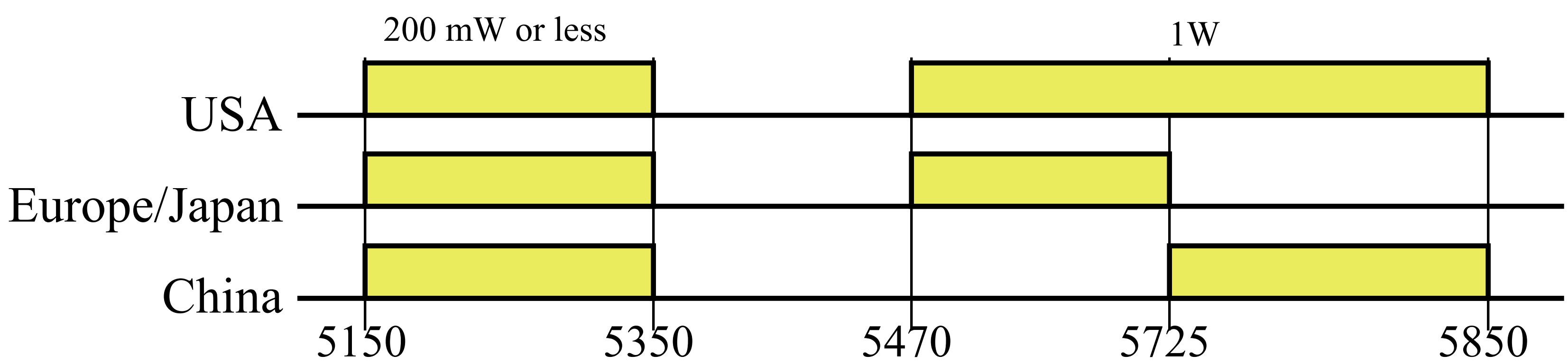
Dynamic TDD (Cont)

- Too many U's or D's in a row delay acks/nacks and affect the usefulness of HARQ.
- Release 12 added flexible "F" subframes that can be declared as S, D, or U $\Rightarrow$ Can change every 10 ms.
- **Enhanced Interference Mitigation and Traffic Adaptation (eIMTA):** Cells can change UL/DL pattern as needed. Mobiles asked to transmit at higher power if needed.
- This will be further enhanced for 5G

TTI index									
0	1	2	3	4	5	6	7	8	9
D	S	U	F	F	D	S/D	F	F	F

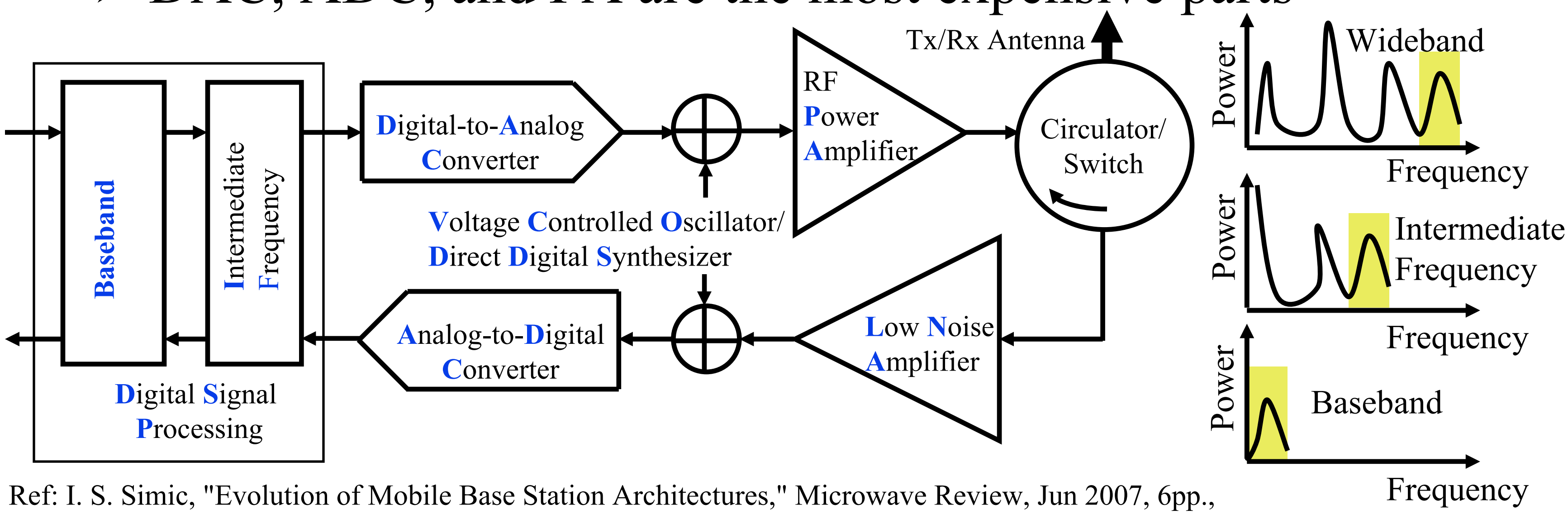
License Assisted Access (LAA)

- A.k.a. unlicensed LTE (LTE-U). Release 13.
- 5 GHz band for public hot-spots and in-building
- Different rules and bands in different countries, e.g.,
  - Avoid if a radar is operating
  - Can't block 20 MHz if using only 180 kHz
  - Transmit only if free. Recheck after maximum occupancy time ⇒ Can not transmit continuously as in standard LTE
- End-to-End LTE ⇒ Better integration than with WiFi
- May use as a downlink-only carrier aggregation



Multimode Base Stations

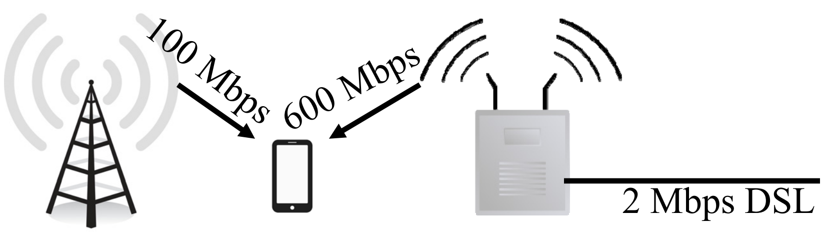
- 2G/3G/4G/WiFi/WiMAX, multi-band, multi-frequency, multiple modulation formats, multiple air interfaces
- Need "Software Define Radios (SDRs)"
  - Analog signal is sampled at a very high rate and processed using digital signal processing (DSP)
  - DAC, ADC, and PA are the most expensive parts



Ref: I. S. Simic, "Evolution of Mobile Base Station Architectures," Microwave Review, Jun 2007, 6pp., http://www.mtt-serbia.org.rs/microwave_review/pdf/Vol13No1-07-ISimic.pdf

Intelligent Multi-Mode RAT Selection

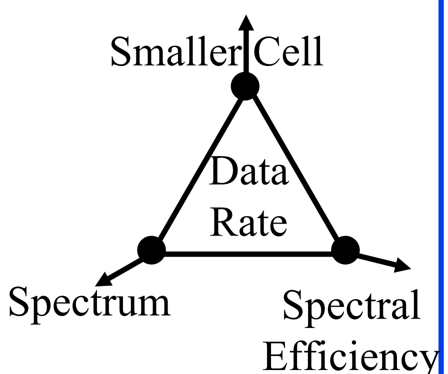
- Selecting between LTE, WiFi, 3G, …
- Can not just select
  - Highest speed
  - Highest signal power
  - Cheapest
- Correct choice also depends upon the type of traffic: voice vs. data ⇒ Network assisted selection



Ref: 4G Americas, "Integration of Cellular and WiFi Networks," Sep 2013, 65 pp., http://www.4gamericas.org/files/3114/0622/2546/Integration_of_Cellular_and_WiFi_Networks_White_Paper-_9.25.13.pdf

Hyper-Dense Small Cells

- Used in extremely busy areas. Sports arena, Malls, Metro trains $\Rightarrow$ Heterogeneous and Small Cell Network (HetSNets)
- Self-Organizing: Neighbor discovery, parameter setting,
- Backhaul Flexibility: DSL, HomePlug, Wireless, …
- Mobility-Management:
  - Frequent Handovers Mitigation: Ping-pong. Network assisted as in intelligent multi-mode RAT selection
  - Forward Handover: Small cell can prefetch user context from the Serving cell
- Load balancing between small cells and with macro cell
- Multi-RAT Management: 2G/3G/4G/WiFi
- Privately Owned: Security and Incentive issues



Ref: I. Hwang, B. Song, and S. S. Soliman, "A Holistic View on Hyper-Dense Heterogeneous and Small Cell Networks," IEEE Communications Magazine, Jun 2013, pp. 20-27, http://blog.sciencenet.cn/home.php?mod=attachment&id=62246

New Energy Saving Mechanisms

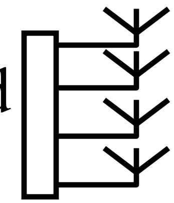
1. Discontinuous Transmission (DTX)
2. Antenna Muting
3. Cell on/off switching
4. Power Save Mode for IoT

Discontinuous Transmission (DTX)

- Do not transmit during silence $\Rightarrow$ Resources can be reused by others
- Was difficult to do in static allocation like GSM
- Already part of LTE

Antenna Muting

- Base stations have multiple antenna for MIMO
- Antenna Muting: Turn off some antenna at low load



- Advantage: Energy savings
- Problem: Number of antenna is assumed fixed and each antenna has its own pilot signals
  - Space-Frequency Block Code (SFBC) is used to transmit different frequency components from different antenna
  - ⇒ Throughput reduces
- Studies have shown significant energy savings with acceptable loss in throughput at low load.
- In 5G number of Antenna will become dynamic

Ref: P. Skillermark and P. Frenger, "Enhancing Energy Efficiency in LTE with Antenna Muting," 75th Vehicular Technology Conf. (VTC Spring), Yokohama, 2012, pp. 1-5, https://pdfs.semanticscholar.org/29ec/17e00ccae04ae34b74f9e6e62c1e2c42d789.pdf

Cell On/Off Switching

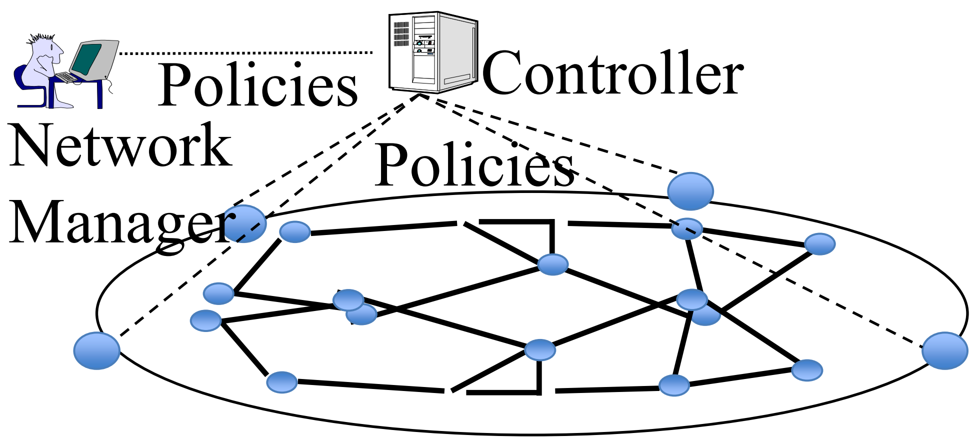
- Under low load a cell or small cell can be turned off
- Off cells broadcast "Discovery reference signals (DRS)" periodically so that they can be turned on if necessary
- Takes a few hundred ms
- Used for energy consumption during nights

CapEx/OpEx Reduction Techniques

1. Software Defined Networking (SDN)
2. Network Function Virtualization (NFV)
3. Mobile Edge Computing (MEC)
4. Cloud Radio Access Network (C-RAN)

Software Defined Networking (SDN)

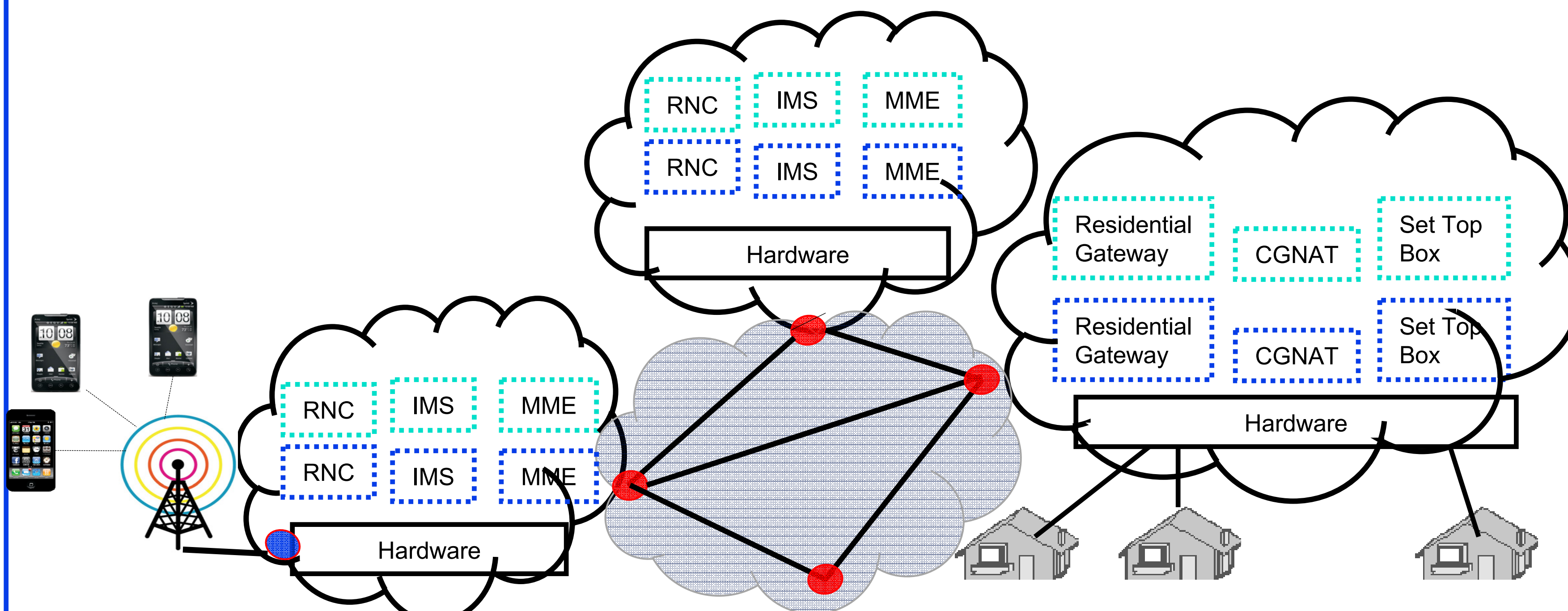
1. **Abstract the Hardware**: No dependence on physical infrastructure. Software API.
2. **Programmable**: Shift away from static manual operation to fully configurable and dynamic
3. **Centralized Control of Policies**: Policy delegation and management



Ref: D. Batista, et al, "Perspectives on software-defined networks: interviews with five leading scientists from the networking community" Journal of Internet Services and Applications 2015, 6:22, http://www.cse.wustl.edu/~jain/papers/jisa15.htm

Network Function Virtualization

- Standard hardware is fast and cheap ⇒ No specialized hardware
- Implement all functions in software
- Virtualize all functions ⇒ Cloud ⇒ Create capacity on demand



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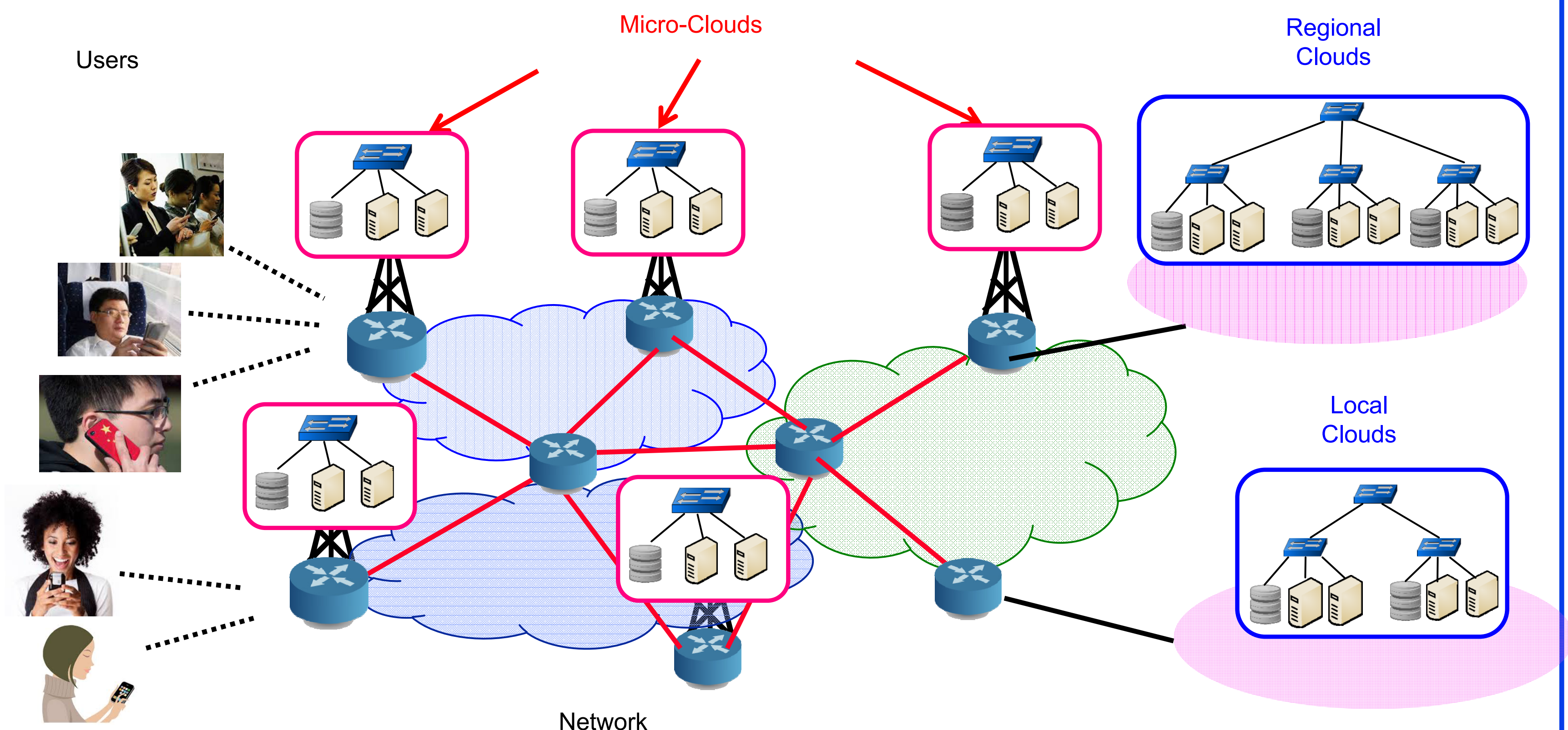
Mobile Edge Computing (MEC)

- To service mobile users/IoT, the computation needs to come to edge ⇒ Mobile Edge Computing



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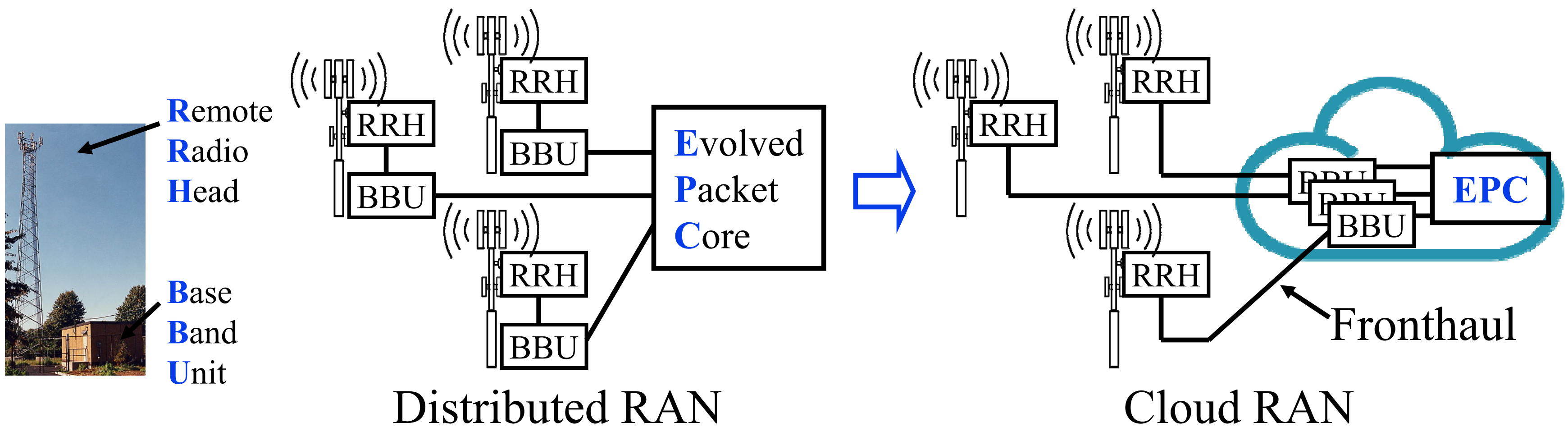
Cloud Radio Access Network (C-RAN)

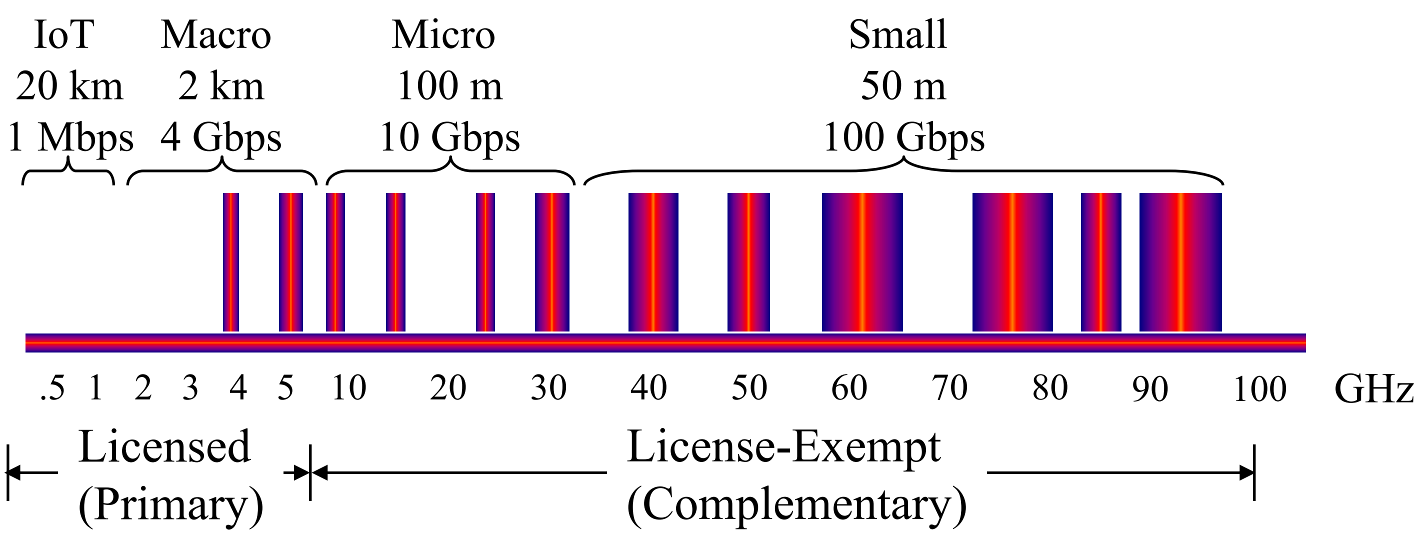
- Centralize baseband processing in a cloud
- Need to carry high-bit rate signal (after A-to-D conversion) from tower to cloud site ~ 10 Gbps
- Optical fiber, 10 Gbps Ethernet, Microwave can be used depending upon the distance ~ 1-20 km of **fronthaul**
- Particularly good for dense small cells. Multi-provider support.



Ref: C. I, et al, "Recent Progress on C-RAN Centralization and Cloudification," IEEE Access, Vol. 2, 2014, pp. 1030-1039, http://ieeexplore.ieee.org/iel7/6287639/6514899/06882182.pdf?arnumber=6882182

New Spectrum

- ITU estimates 900-1420 MHz required for 4G/5G by 2020 and 440-540 MHz required for 2G/3G and their enhancements



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Above 6 GHz

- Free-space loss increases in proportion to square of frequency and square of distance. 88 dB loss with 30 GHz at 20 m $\Rightarrow$ 10-100 m cell radius
- Outdoor-to-Indoor: Glass windows add 20-40 dB
- Mobility: Doppler shift is proportional to frequency and velocity. Multipath results in varying Doppler shifts $\Rightarrow$ Lower mobility
- Wide Channels: Duplex filters cover only 3-4% of center frequency $\Rightarrow$ Need carrier aggregation.
- Antenna: 8x8 array at 60 GHz is only 2cm x 2cm. A/D and D/A converters per antenna element may be expensive
- 2 Gbps to 1 km is feasible using mm waves

Ref: ITU-R M2376-0, "Technical Feasibility of IMT in bands above 6 GHz," July 2015, http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2376-2015-PDF-E.pdf

Application Specific Improvements

- Internet of Things
- Video

LTE Applications

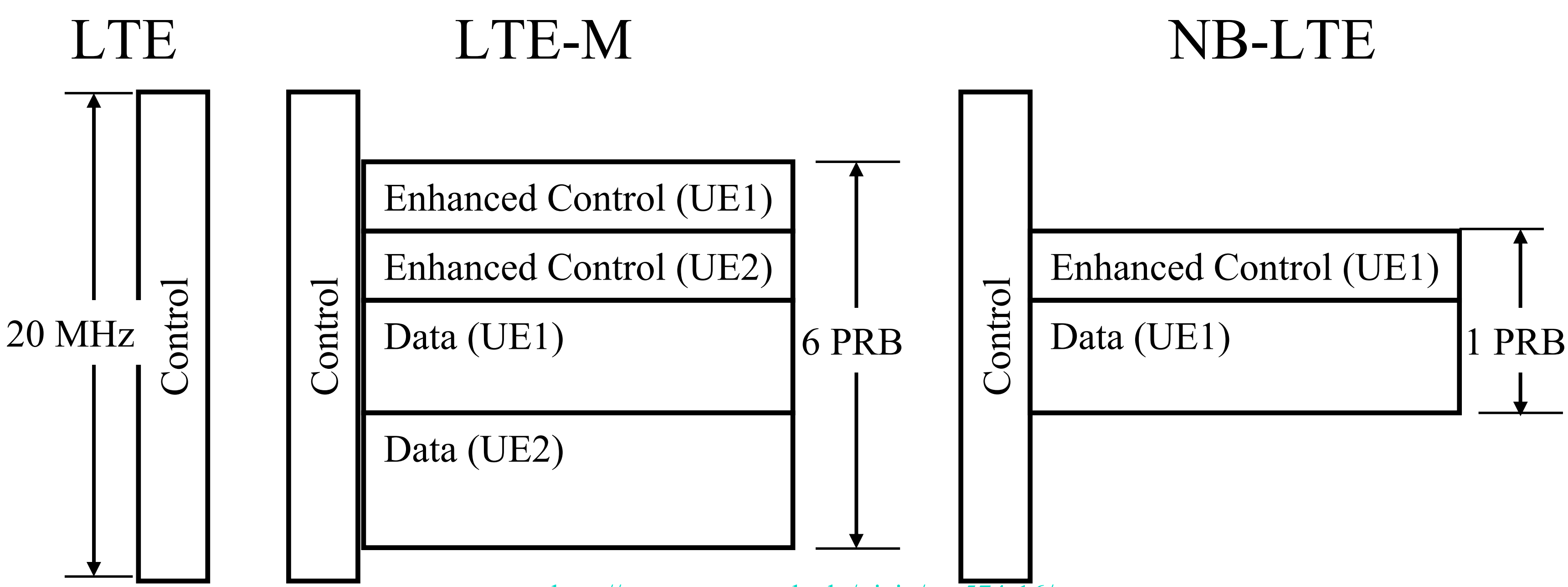
- Machine Type Communication (MTC): M2M or IoT
  - Versus current Human Type Communication (HTC)
  - GSM and HSPA modems for ~$5 are potential choices
  - Extended Coverage GSM (EC-GSM): Half-duplex FDD, Power Saving Mode (Same as LTE), 20 dB enhancements in link budget (total 164 dB) in R13 ⇒ 7x range for low rate
- Device-to-Device (D2D): Proximity services (Nearby search), enable direct device-to-device communication if nearby.
  - Low Latency D2D: Vehicular networking
- Group Communication: Public Safety (Fire, Police), push-to-talk
- Enhanced Multimedia Broadcast Multicast System (eMBMS): Broadcast Services (TV)

Machine Type Communication

- **LTE Low-cast (Category 0) UE**: In Release 12.
  - Single Antenna
  - Reduced peak rate up to 1 Mbps
  - Half-Duplex ⇒ No duplex filter
  - Power saving mode (PSM)
- **MTC LTE (LTE-M) (Category -1)** UE: In Release 13.
  - 1 Mbps using 1.4 MHz = 6 Physical Resource Blocks (PRB)
  - All power on fewer subcarriers
    ⇒ **P**ower **S**pectral **D**ensity (**PSD**) Boosting
    ⇒ 15 dB reduction in link budget by PSD and repetition
    ⇒ Allows UEs in basements and indoors
  - Reduced Tx power to 20 dBm ⇒ integrated amplifier
- **Narrow Band LTE** (**NB-LTE**) introduced Category -2 UE:
  - 128 kbps using 200 kHz band = Single PRB
  - 23 dBm power (required to maintain the link budget)
- Both LTE-M and NB-LTE UEs use single RF chain

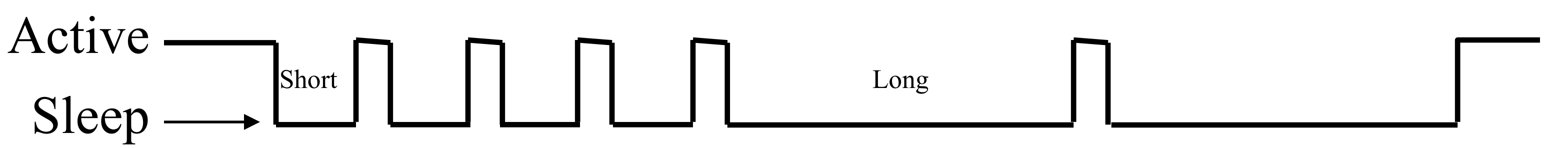
Signaling Enhancements for MTC

- **E**nhanced **P**hysical **D**ownlink **C**ontrol **Ch**annel (EPDCCH)
- LTE Cat 0 UE receive signaling in the entire 20 MHz band
- LTE-M UEs receive signaling in their 1.4 MHz band
- For NB-LTE UEs, signaling is part of the assigned PRB



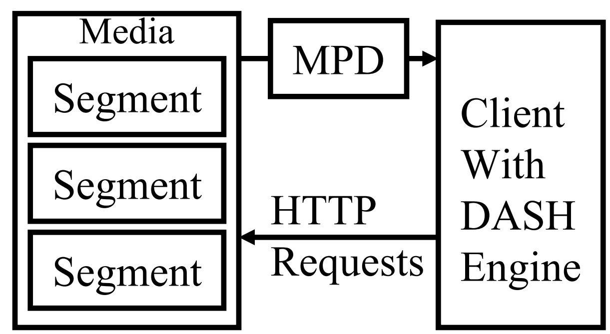
Power Saving Mode (PSM)

- Discontinuous Reception (DRX). Introduced in Release 12
- Allows UE to stay registered while sleeping
- UE's need to monitor resource allocation channel even if it has nothing to send or receive
- Connected mode DRX (cDRX): UE can sleep and periodically wake up to check the control channel
  - Short sleep cycle: 5 to 400 ms
  - Long sleep cycle: 20 ms to 2.5s (if no activity for 4 short cycles)



Dynamic Adaptive Streaming over HTTP (DASH)

- Video is the major component of mobile traffic
  $\Rightarrow$ DASH provides an efficient method for video streaming
- Standard developed jointly by 3GPP, ISO, Open IPTV Forum
- Standard Web Servers: No changes required to servers, Content Distribution Networks (CDN), or HTTP protocol. HTTP passes easily through firewalls
- Mobile client controls what is downloaded using a "media presentation description (MPD)" file defined by DASH
- MPD contains URLs for segments
- Client requests segments as needed. Allows fast forward, rewind, etc.



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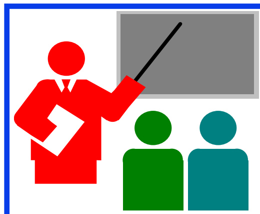

Summary

1. Current IMT Vision document defines 5G in terms of 8 parameters: a peak rate up to 20 Gbps per user, User experienced rate of 100 Mbps, spectral efficiency 3 times of 4G, Mobility support to 500 km/h, a latency of 1 ms, a density of a million connections per m2, energy efficiency 100x of 4G, and traffic capacity of 10 Mbps/m2.
2. New radio multiplexing techniques include f-OFDM, FBMC, NOMA, PDMA, LDS, SCMA, and IDMA
3. New spectrum utilization techniques include 3D Beamforming, Massive MIMO, FDD-TDD Carrier Integration, DAS, Simultaneous Transmission and Reception, Dynamic TDD, LAA, Multimode Base Stations, Intelligent Multi-Mode RAT Selection, and Higher order modulations in small cells
4. New energy savings mechanisms include Discontinuous Transmission (DTX), Antenna Muting, Cell on/off switching, and Power Save Mode for IoT
5. Capex/OpEx reduction techniques include SDN, NFV, MEC, and C-RAN.
6. Application specific improvements include LTE-M, NB-LTE for IoT and DASH for video.
7. New license-exempt spectrum in 6GHz-100 GHz will complement the licensed spectrum.

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- https://en.wikipedia.org/wiki/Discontinuous_transmission
- https://en.wikipedia.org/wiki/Software-defined_networking
- https://en.wikipedia.org/wiki/Network_function_virtualization
- https://en.wikipedia.org/wiki/Mobile_edge_computing
- https://en.wikipedia.org/wiki/C-RAN
- https://en.wikipedia.org/wiki/Small_cel l
- https://en.wikipedia.org/wiki/Distributed_antenna_system
- https://en.wikipedia.org/wiki/Dynamic_Adaptive_Streaming_over_HTTP
- https://en.wikipedia.org/wiki/3GPP
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Acronyms

- 3GPP 3rd Generation Partnership Project
- ADC Analog-to-Digital Converter
- API Application Programming Interface
- AWGN Additive White Gaussian Noise
- BBU Broadband Unit
- BS Base Station
- CapEx Capital Expenditure
- CDMA Code Division Multiple Access
- CDN Content Distribution Networks
- cDRX Connected mode discontinuous reception
- CGNAT Carrier Grade Network Address Translator
- DAC Digital-to-Analog Converter
- DAS Distributed Antenna Systems
- DASH Dynamic Adaptive Streaming over HTTP
- dB DeciBel
- dBm DeciBel Milliwatt

Acronyms (Cont)

DL	Downlink
DRS	Discovery reference signals
DRX	Discontinuous Reception
DS-CDMA	Direct Sequence Code Division Multiple Access
DSL	Digital Subscriber Line
DSP	Digital signal processing
DTX	Discontinuous Transmission
eIMTA	Enhanced Interference Mitigation and Traffic Adaptation
eMBMS	Enhanced Multimedia Broadcast Multicast System
eNB	Evolved Node-B
EPC	Evolved Packet Core
EPDCCH	Enhanced Physical Downlink Control Channel
FBMC	Filtered Bank Multicarrier
FD-MIMO	Full Dimension MIMO
FDD	Frequency Division Duplexing
GHz	Giga Hertz

Acronyms (Cont)

- GSM Global System for Mobile Telephony
- HARQ Hybrid Automatic Repeat Request
- HetSNets Heterogeneious Small Cell Network
- HSPA High Speed Packet Access
- HTC Human Type Communication
- HTTP Hyper-Text Transfer Protocol
- IDMA Interleave Division Multiple Access
- IEEE Institution of Electrical and Electronic Engineers
- IMS IP Multimedia System
- IMT-2020 5G
- IMT International Mobile Telecommunications
- IoT Internet of Things
- IPTV Internet Protocol Television
- ISO International Standards Organization
- ITU-R International Telecommunications Union- Radio
- ITU International Telecommunications Union

Acronyms (Cont)

- kHz Kilo Hertz
- LAA License Assisted Access
- LDS Low Density Spreading
- LTE-A Long-Term Evolution Advanced
- LTE-M Long-Term Evolution for Machine Type Communication
- LTE-U Long-Term Evolution Unlicensed
- LTE Long-Term Evolution
- MC-CDMA Multi-carrier Code Division Multiple Access
- MEC Mobile Edge Computing
- MHz Mega Hertz
- MIMO Multiple Input Multiple Output
- MME Mobility Management Entity
- MPD Media presentation description
- MTC Machine Type Communication
- mW Milli Watt
- NB-LTE Narroband Long Term Evolution

Acronyms (Cont)

- NFV Network Function Virtualization
- NOMA Non-Orthogonal Multiple Access
- OFDM Orthogonal Frequency Division Multiplexing
- OFDMA Orthogonal Frequency Division Multiple Access
- OpEx Operational Expenditure
- PA Power Amplifier
- PDMA Pattern Division Multiple Access
- PHY Physical Layer
- PRB Physical Resource Blocks
- PSD Power Spectral Density
- PSM Power Saving Mode
- QAM Quadrature Amplitude Monitor
- QoE Quality of Experience
- QoS Quality of Service
- RAN Radio Access Network
- RAT Radio Access Technology

Acronyms (Cont)

REC	Recommendation
REP	Report
RF	Radio Frequency
RNC	Radio Network Controller
RRH	Remote Radio Head
SCMA	Sparse code multiple access
SDN	Software Defined Networking
SDR	Software Defined Radios
SFBC	Space-Frequency Block Code
SIC	Successive Interference Cancellation
TDD	Time Division Duplexing
TV	Television
UE	User Element
UL	Uplink
URL	Uniform Resource Locator
USA	United States of America

Acronyms (Cont)

- VTC Vehicular Technology Conference
- WCSP Wireless Communications and Signal Processing
- WiFi Wireless Fidelity
- WiMAX Worldwide Interoperability for Microwave Access

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http://www.cse.wustl.edu/~jain/cse574-16/j_15cel.htm

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