Feasibility Study of Cloud SDR

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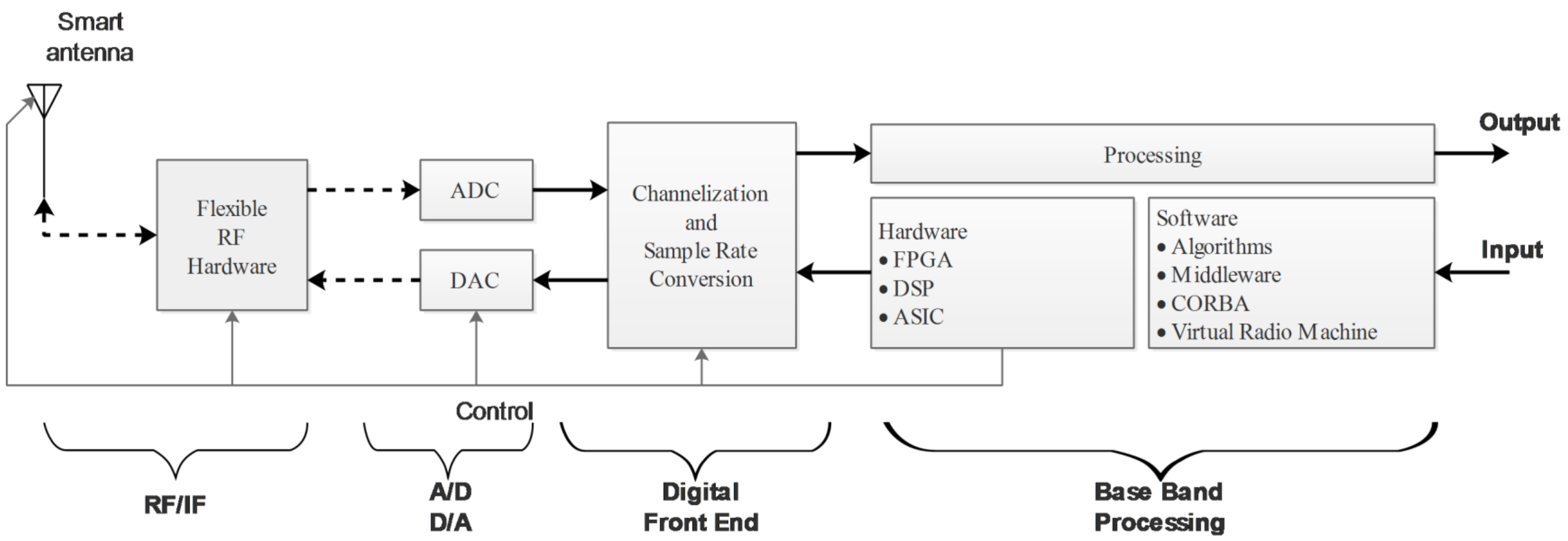
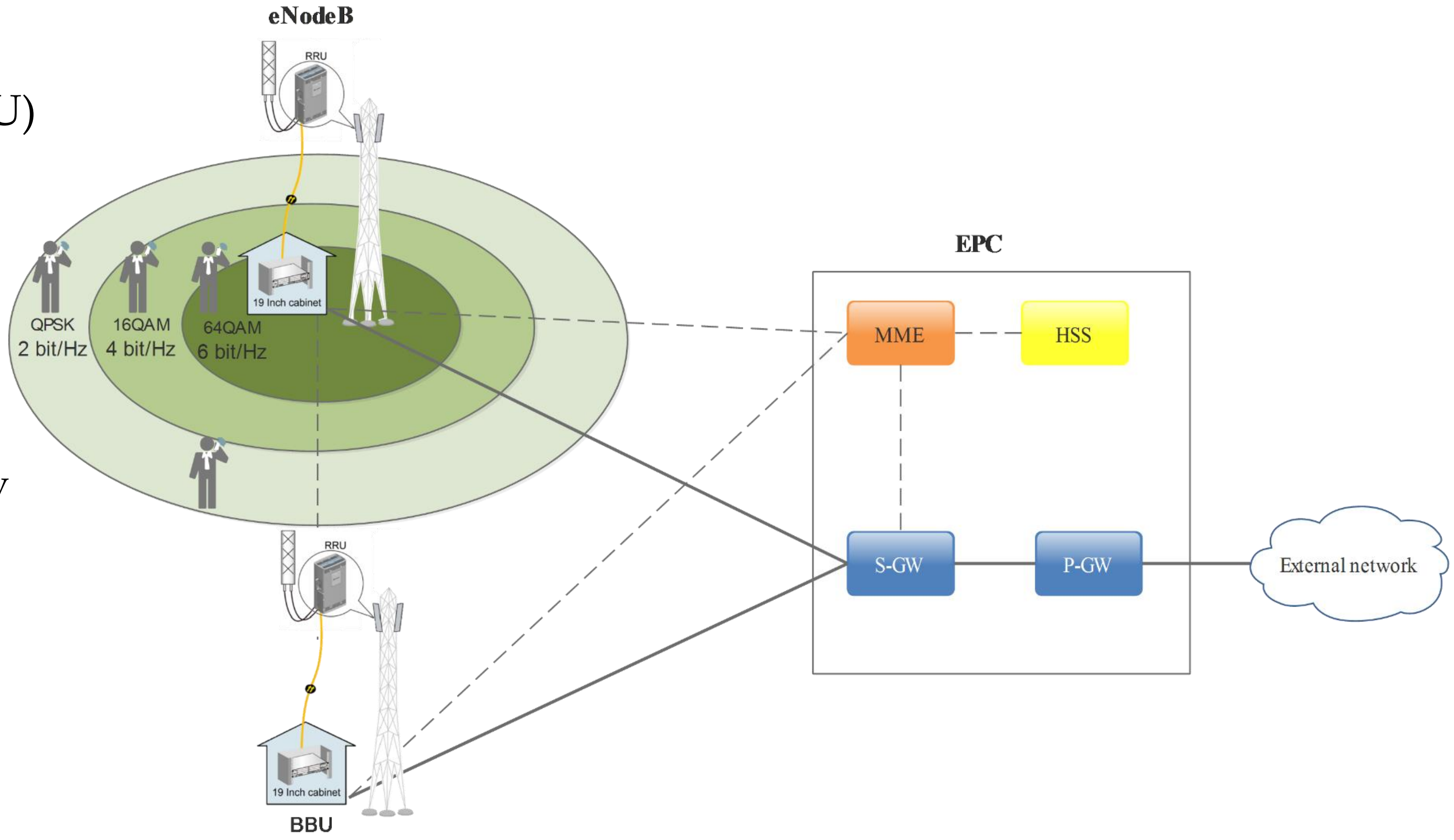
What is SDR?

- SDR is a radio that some or all of the physical layer functions are defined by software
  - The ideal SDR hardware should support any waveform at any carrier frequency!?



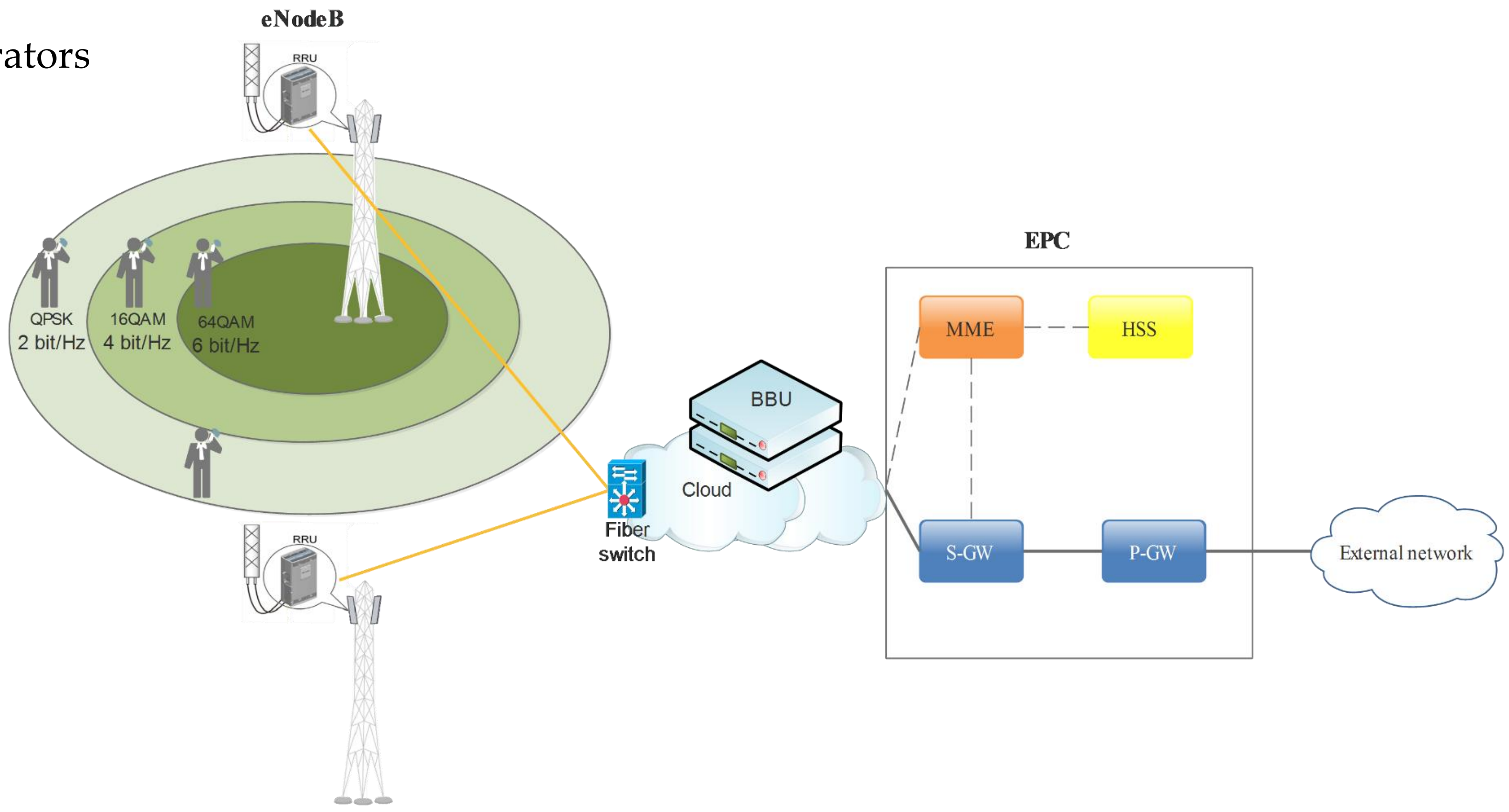
LTE Architecture

- Access network
  - eNodeB
    - Remote Radio Unit (RRU)
    - Baseband Unit (BBU)
  - Backhaul
- Core network
  - Mobility Management Entity
  - Serving Gateway
  - Packet Data Network Gateway
  - Home Subscriber Server



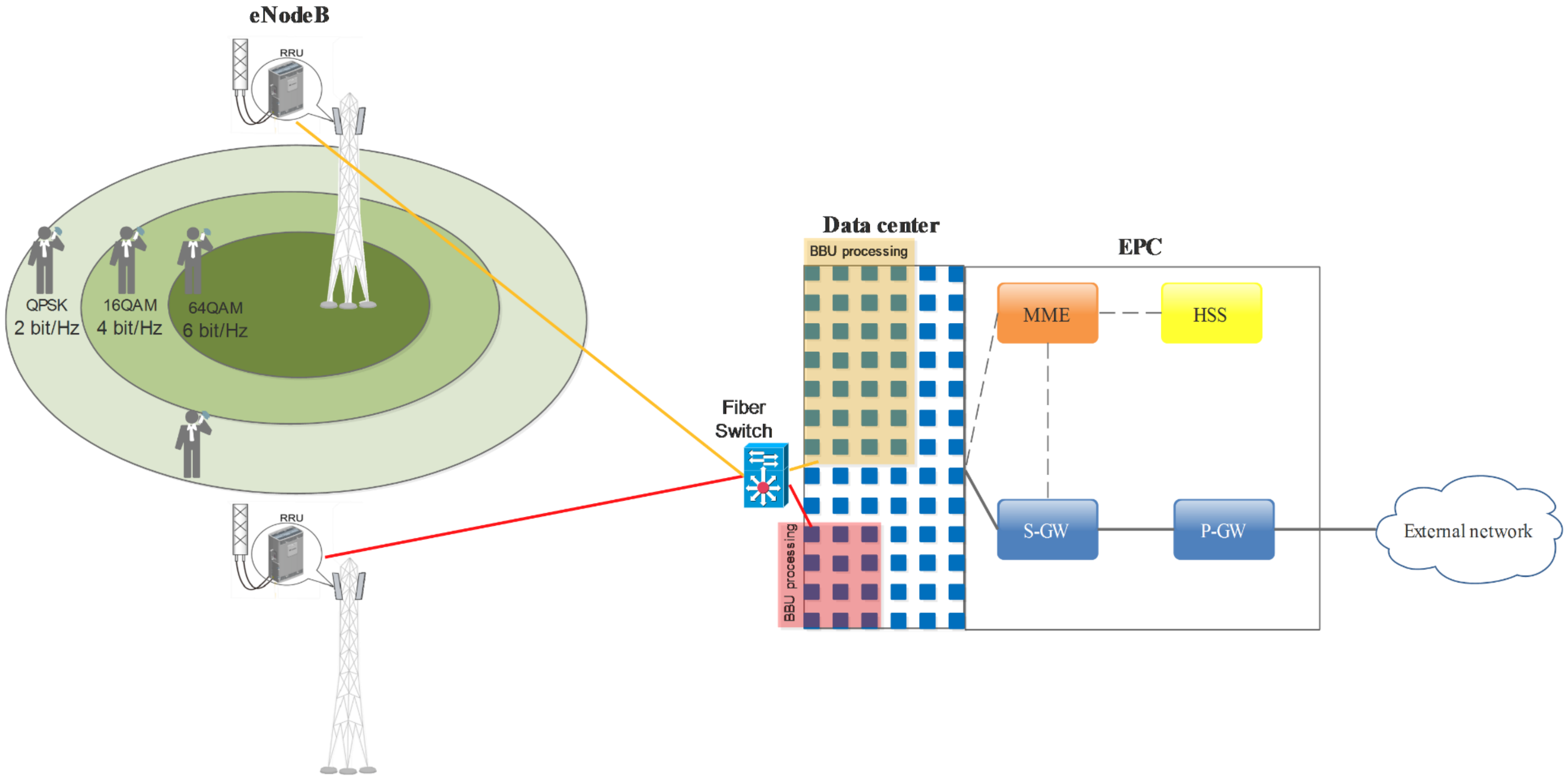
Cloud SDR

- Centralized management
- Lower total cost of ownership
- Better coordination between operators
- High processing power
- Resource pooling
- Save power

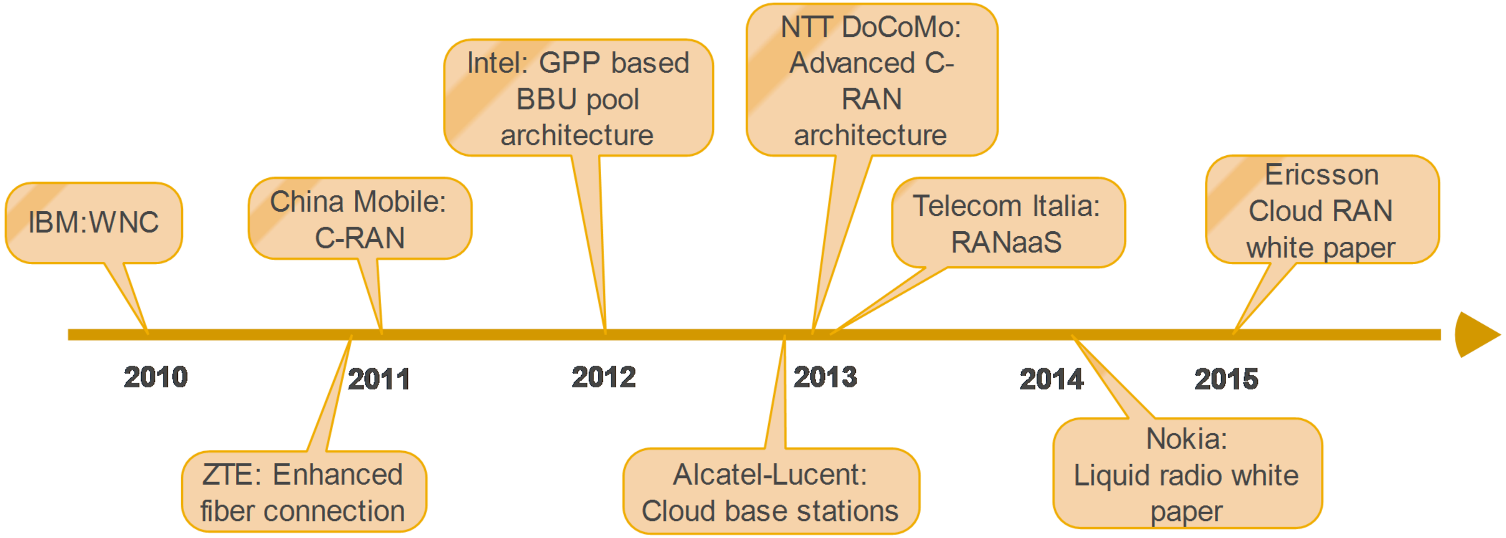


Cloud Resource Pool

- Cloud SDR provides processor pool for eNB whenever its BBU demands higher processing power

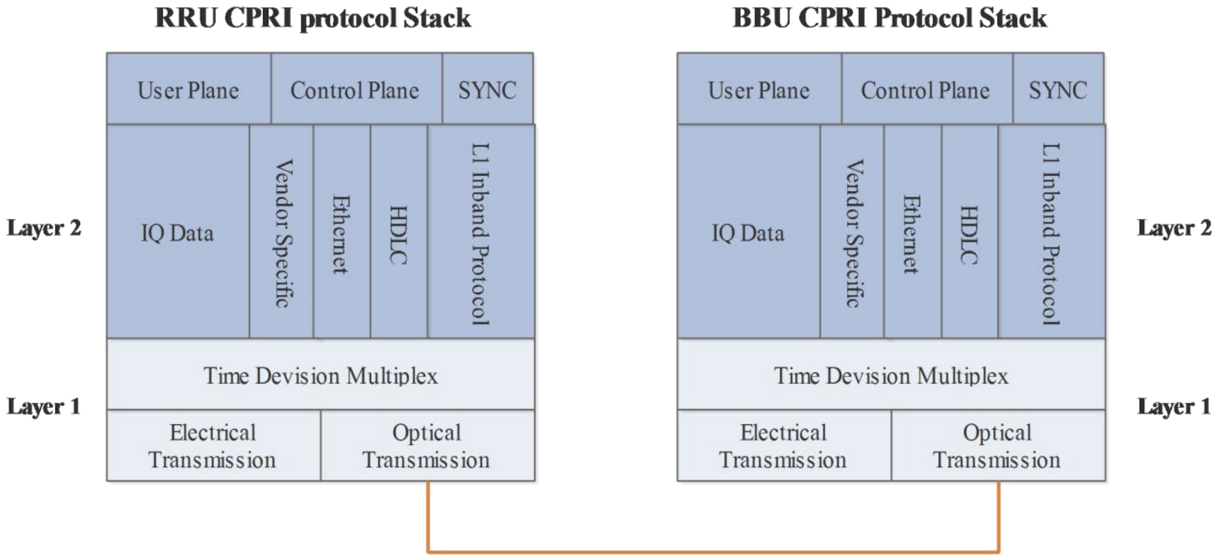


CRAN industry trend

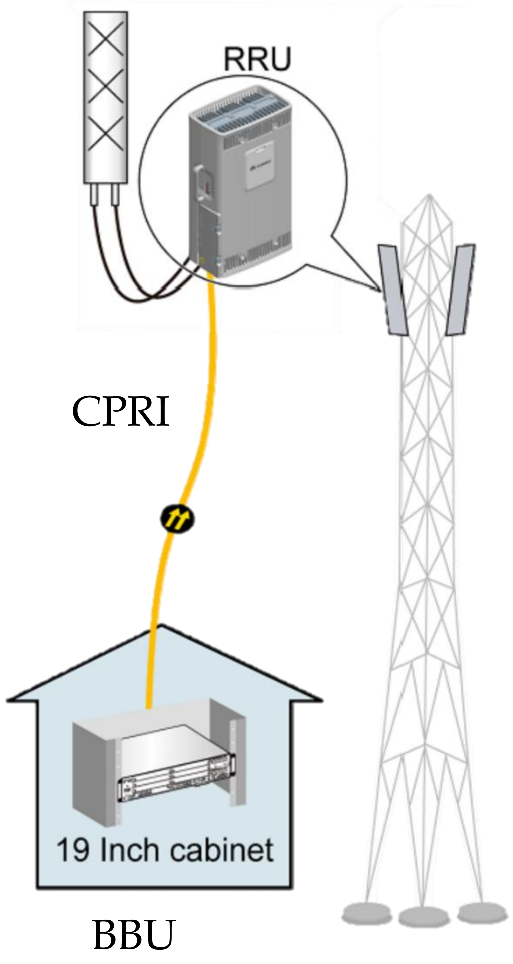


Infrastructure Feasibility

- Common Public Radio Interface (CPRI) [1]
  - Connect antenna systems to remote processing unit.

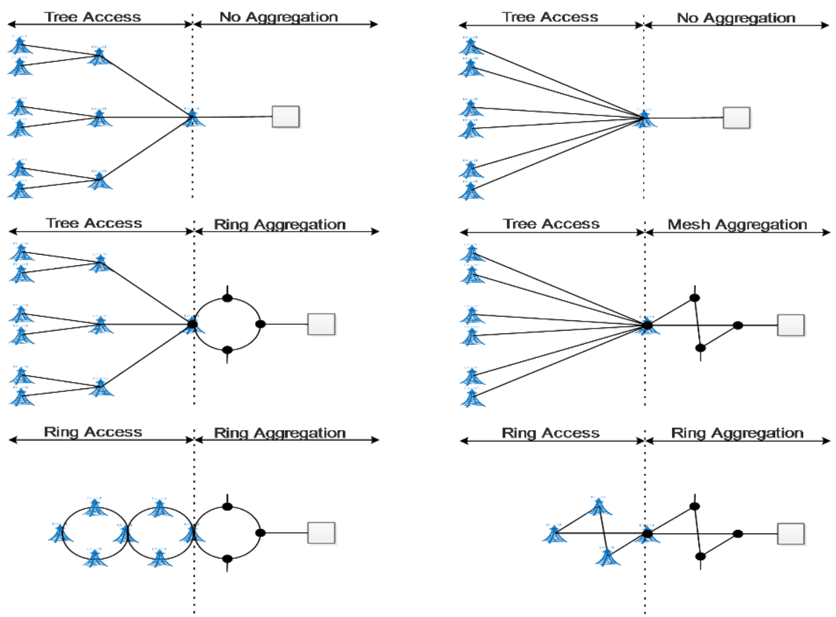


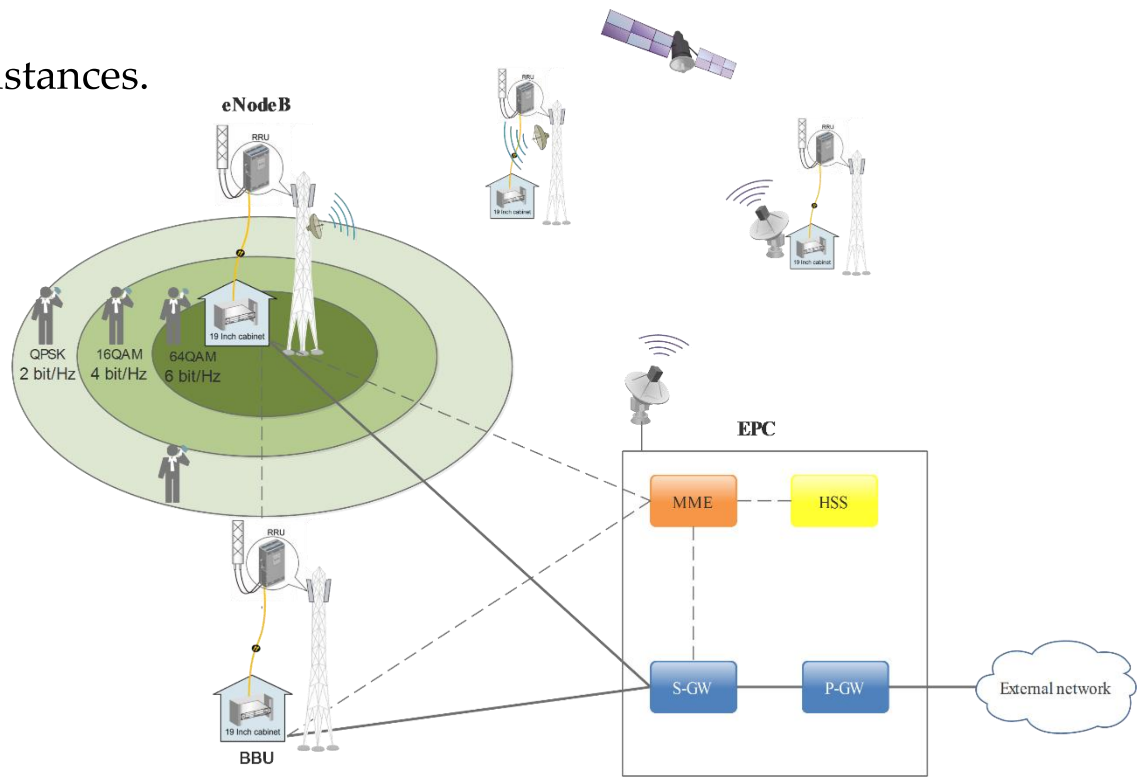
Each 20MHz LTE antenna carrier requires ~1 Gbps CPRI line



Infrastructure Feasibility

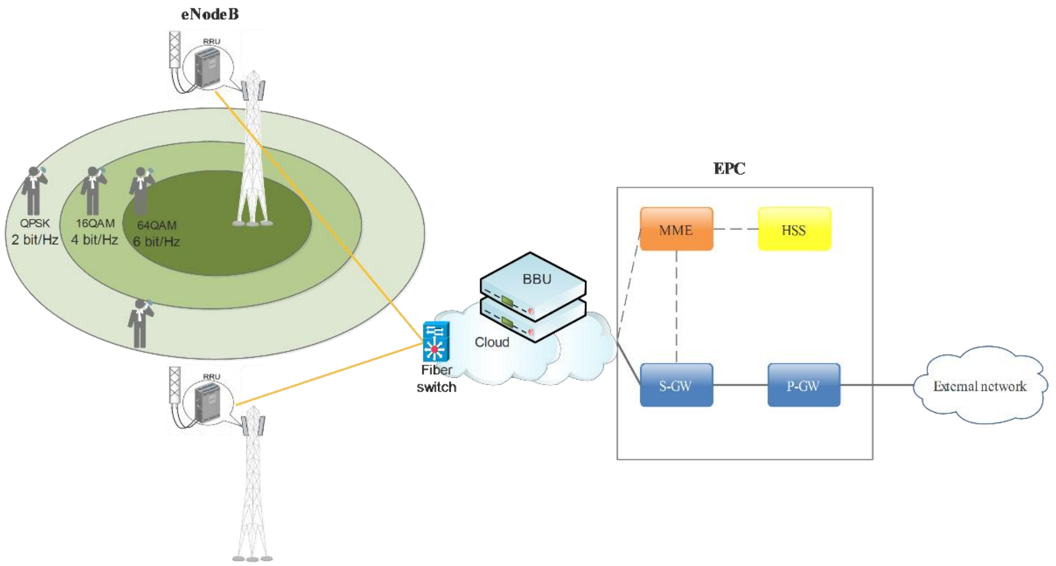
- Backhaul network [2]
  - Comprises the intermediate links between the core network and edge network.
  - Microwave link 6-42 GHz and E-band 70-80 GHz support more than 10 Gbps backhaul
  - Satellite backhaul introduces latency
  - Fiber link can support more than 101 Tbps in longer distances.





Latency

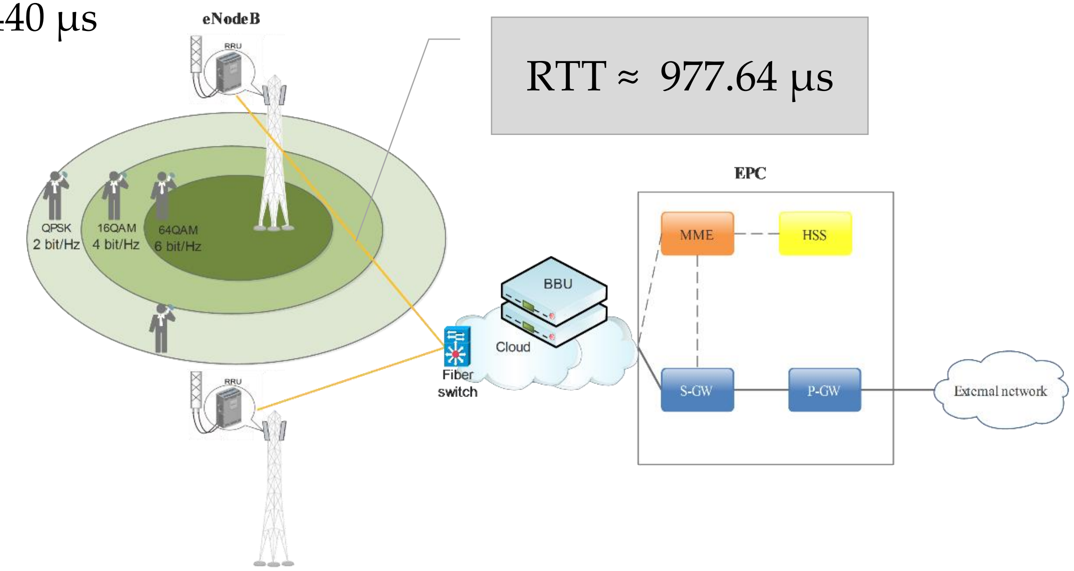
- Latency and overall throughput dominated by two factor:
  - Distance
  - Protocols
- Latency causes:
  - Propagation delay = distance / speed
  - Serialization = packet size in bits / transmission rate in bits per second
  - Data protocols
    - TCP handshakes and window size
  - Routing and switching
    - Vendor dependent
  - Queuing and buffering
    - Queue awaiting transmission due to over-utilization



Latency

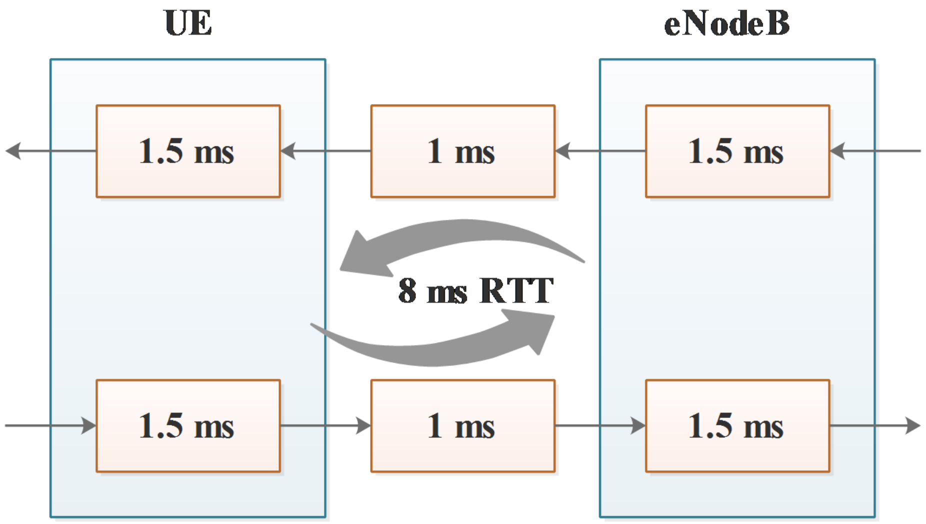
- Latency causes:
  - Propagation delay
    - Fiber propagation delay
      - Fiber distance= speed of light / refractive index ≈ 205 m/µs
      - Fiber latency for 100km ≈ 488 µs
  - Serialization
    - Latency for Ethernet packet 1518 bytes on 10 Gbps line = 1.2144 µs
    - Latency for Ethernet packet 550 bytes on 10 Gbps line = 0.440 µs
  - Routing and switching
    - Fiber switches introduce 380 ns latency
- Round Trip Time:
  - RTT= (488 + 0.440 + 0.380) * 2 ≈ 977.64 µs

RTT ≈ 977.64 µs



LTE Latency [4]

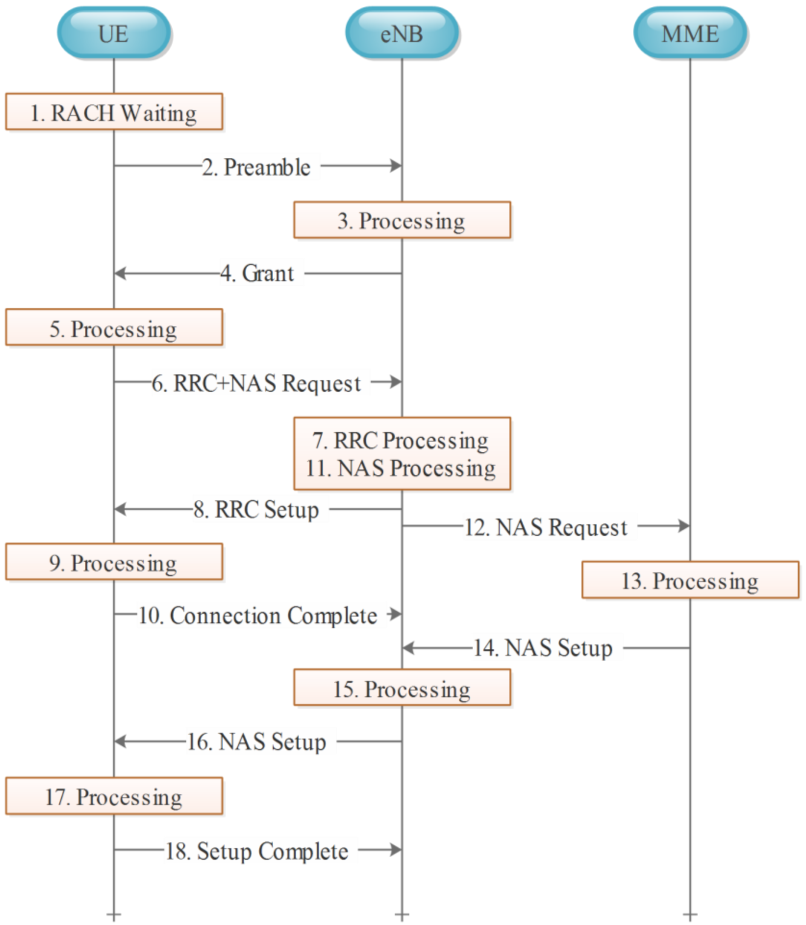
- User plane latency
  - Frequency Division Duplex Radio interface Technology
  - 4 ms when requires no Hybrid Automatic Repeat reQuest (HARQ)



LTE Latency [4]

- Control plane Idle to connected mode latency

Component	Description	Time (ms)
1	Average delay due to RACH scheduling period (1ms RACH cycle)	0.5
2	RACH Preamble	1
3-4	Preamble detection and transmission of RA response (Time between the end RACH transmission and UE's reception of scheduling grant and timing adjustment)	3
5	UE Processing Delay (decoding of scheduling grant, timing alignment and C-RNTI assignment + L1 encoding of RRC Connection Request)	5
6	Transmission of RRC and NAS Request	1
7	Processing delay in eNB (L2 and RRC)	4
8	Transmission of RRC Connection Set-up (and UL grant)	1
9	Processing delay in the UE (L2 and RRC)	12
10	Transmission of RRC Connection Set-up complete	1
11	Processing delay in eNB (Uu → S1-C)	
12	S1-C Transfer delay	
13	MME Processing Delay (including UE context retrieval of 10ms)	
14	S1-C Transfer delay	
15	Processing delay in eNB (S1-C → Uu)	4
16	Transmission of RRC Security Mode Command and Connection Reconfiguration (+TTI alignment)	1.5
17	Processing delay in UE (L2 and RRC)	16
	Total delay	50



LTE Latency [4]

- Control plane Idle to connected mode latency
  - Placing BBU in cloud introduces extra 0.5 ms delay for colored components
  - Total delay ≈ 53 ms

Component	Description	Time (ms)
1	Average delay due to RACH scheduling period (1ms RACH cycle)	0.5
2	RACH Preamble	1
3-4	Preamble detection and transmission of RA response (Time between the end RACH transmission and UE's reception of scheduling grant and timing adjustment)	3
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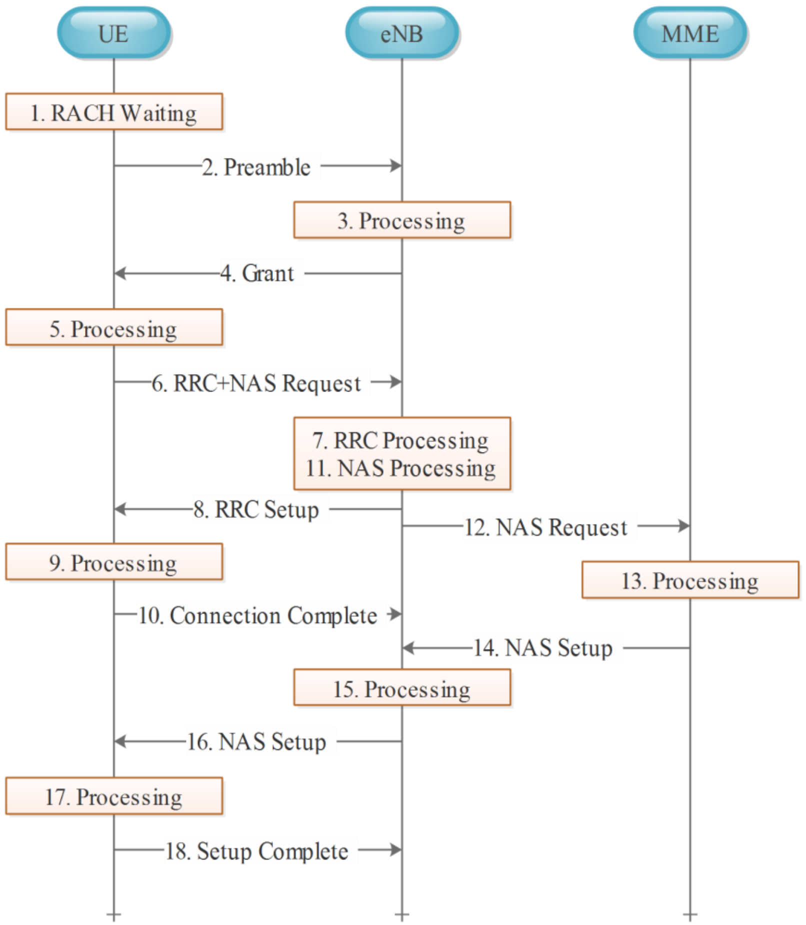
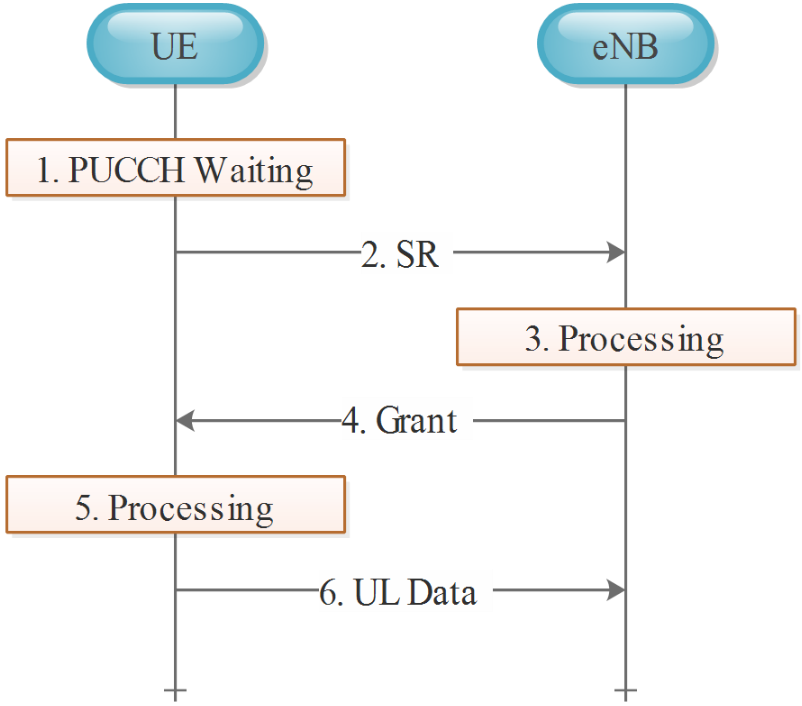


LTE Latency [4]

- Control plane dormant to active mode latency
  - Uplink initiated transition from dormant state to active state for synchronized UE; including first uplink data transmission.

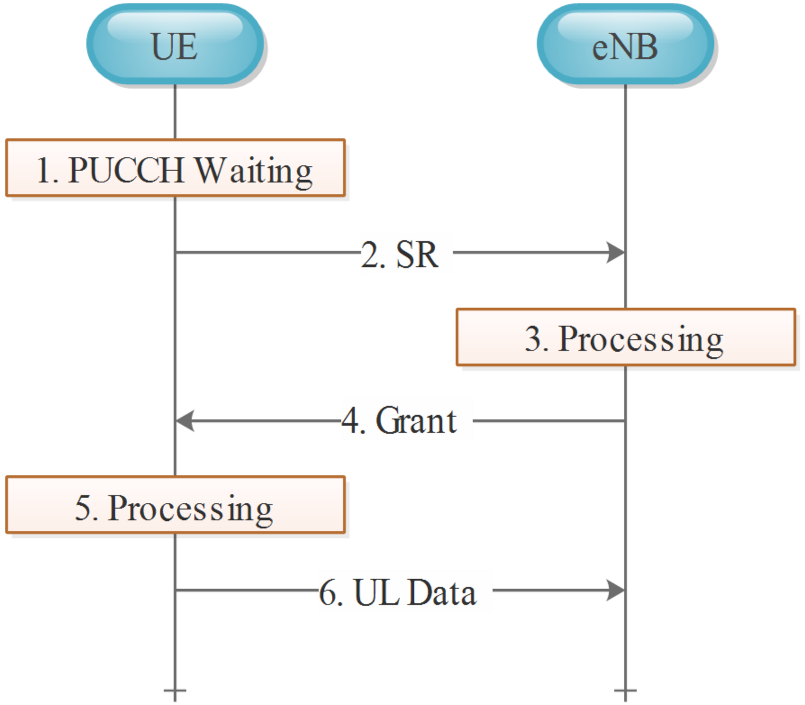
Component	Description	Time [ms]
1	Average delay to next SR opportunity (1ms PUCCH cycle)	0.5
2	UE sends Scheduling Request	1
3	eNB decodes Scheduling Request and generates the Scheduling Grant	3
4	Transmission of Scheduling Grant	1
5	UE Processing Delay (decoding of scheduling grant + L1 encoding of UL data)	3
6	Transmission of UL data	1
	Total delay	9.5



LTE Latency [4]

- Control plane dormant to active mode latency
  - Placing BBU in cloud introduces extra 0.5 ms delay for colored components
  - Total delay ≈ 11 ms

Component	Description	Time [ms]
1	Average delay to next SR opportunity (1ms PUCCH cycle)	0.5
2	UE sends Scheduling Request	1
3	eNB decodes Scheduling Request and generates the Scheduling Grant	3
4	Transmission of Scheduling Grant	1
5	UE Processing Delay (decoding of scheduling grant + L1 encoding of UL data)	3
6	Transmission of UL data	1
	Total delay	9.5



LTE Delay Budget

- LTE includes quality of service management with up to 9 classes of service

QCI	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	2	100 ms	10^{-2}	Conversational Voice
2	4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3	3	50 ms	10^{-3}	Real Time Gaming
4	5	300 ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5	1	100 ms	10^{-6}	IMS Signalling
6	6	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7	7	100 ms	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8	8	300 ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)

LTE Bandwidth vs Distance

- Huawei DBS 3900 eNodeB equipment [5]:
  - The DBS3900 eNodeB supports main LTE FDD frequency bands
  - The RF modules support main LTE FDD frequency bands and the minimum requirement of 2 x 2 uplink and downlink multiple-input multiple-output (MIMO).

Component DBS3900	Description
Maximum Throughput per eNodeB	Downlink: 450 Mbit/s Uplink: 300 Mbit/s
Maximum Number of UEs in RRC-connected Mode per eNodeB	3600
eBBU power consumption	333.5W

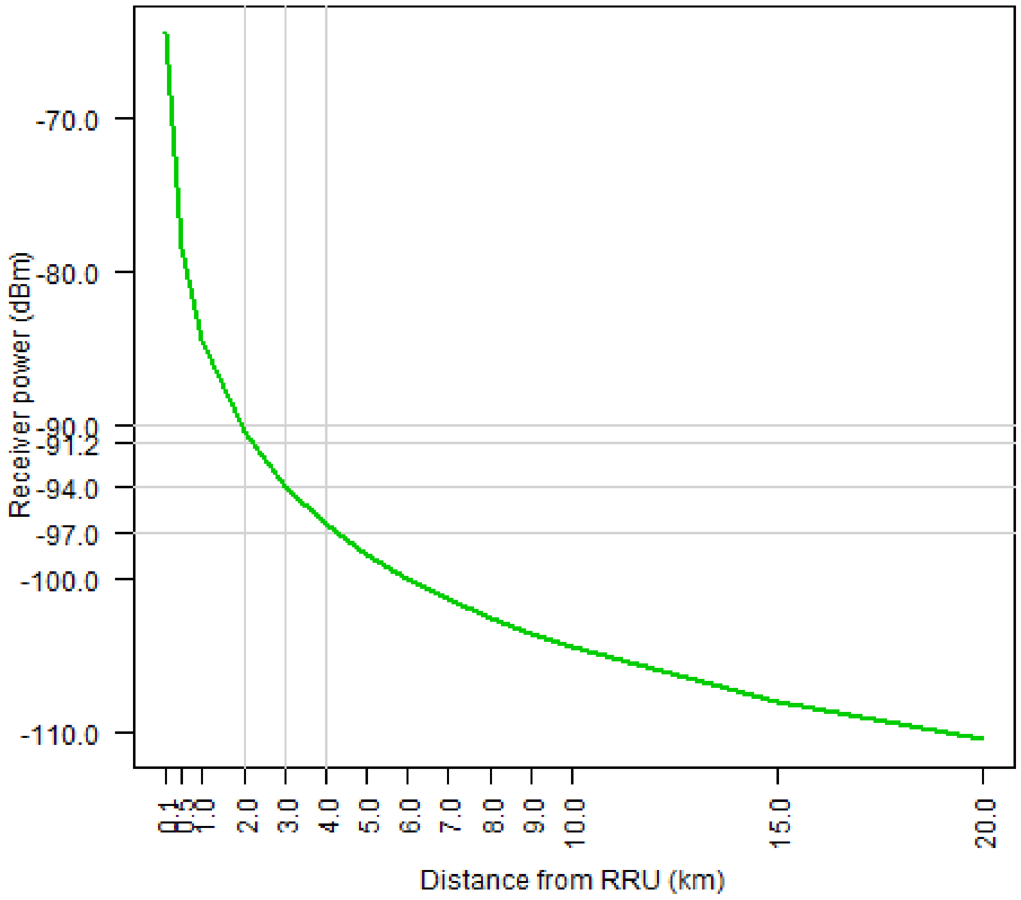
Component RRU3222 (2T2R)	Description
Frequency Band	Frequency Band Bandwidth 800 MHz: Download 791 MHz to 821 MHz Upload 832 MHz to 862 MHz
Bandwidth	5 MHz/10 MHz/20 MHz
eRRU maximum distance	38 km
Maximum eRRU output power	2 × 40W
Receiving sensitivity	1T1R: -106.4dBm 1T2R: -109.2 dBm
eRRU power consumption	300 W

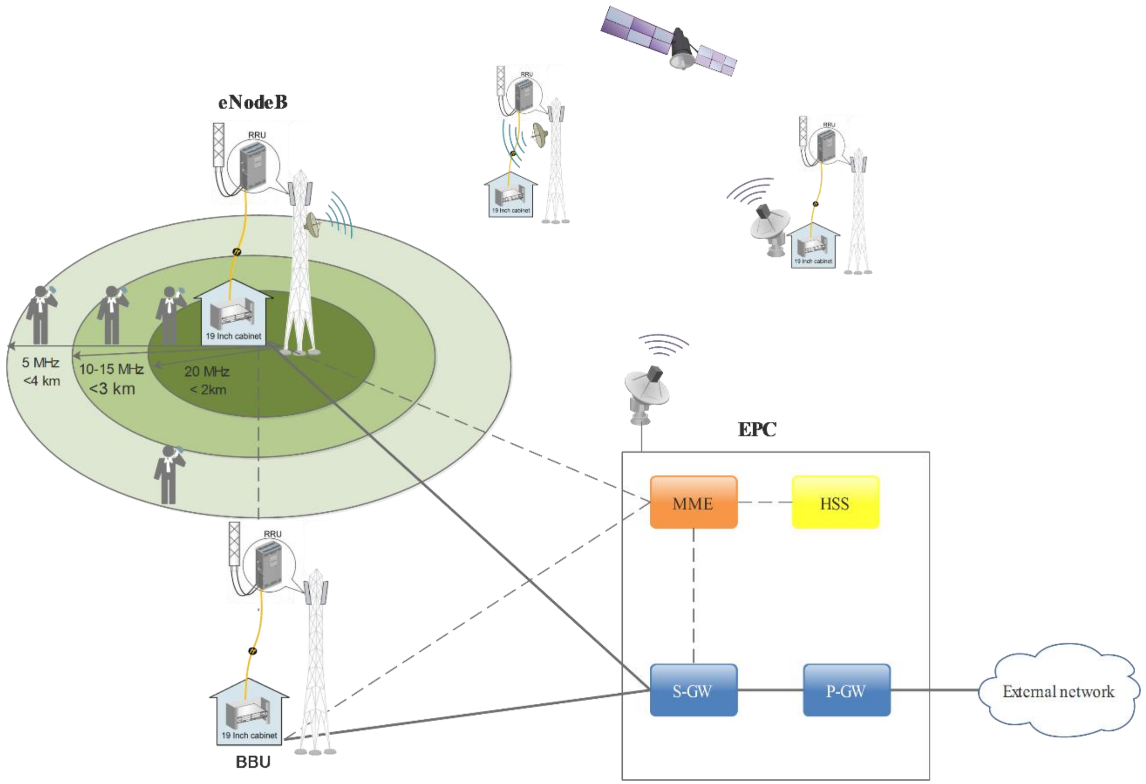
LTE Bandwidth vs Distance

- Receiver Power calculation
  - $P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$
  - Assumptions [6][7]:
    - $P_t = 40\ W,\ G_t = 18\ dBi,\ G_r = 2\ dBi,\ \lambda = 0.375\ m$
  - LTE User Equipment sensitivity [8]:

Band MHz	E-UTRA Band	Uplink Band	Downlink Band	1.4 MHz	3 MHz	5 MHz	10 MHZ	15 MHz	20 MHz
800 FDD	20	832 MHz - 862 MHz	791 MHz – 821 MHz			-97	-94	-91.2	-90
900 FDD	8	880 MHz - 915 MHz	925 MHz - 960 MHz	-102.2	-99.2	-97	-94		
1800 FDD	3	1710 MHz - 1785 MHz	1805 MHz - 1880 MHz	-101.7	-98.7	-97	-94	-92.2	-91
2100 FDD	1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz			-100	-97	-95.2	-94
2600 FDD	7	2500 MHz - 2570 MHz	2620 MHz - 2690 MHz			-98	-95	-93.2	-92
3500 FDD	22	3410 MHz - 3490 MHz	3510 MHz - 3590 MHz			-97	-94	-92.2	-91

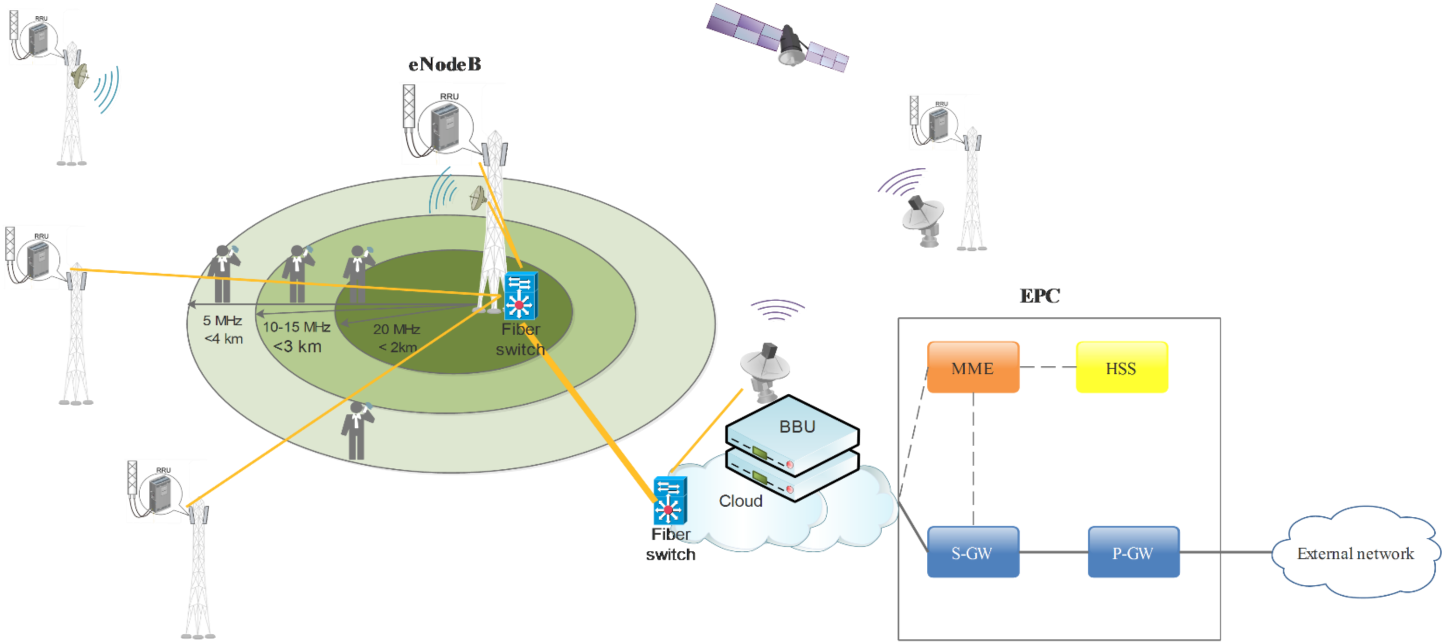
LTE Bandwidth vs Distance





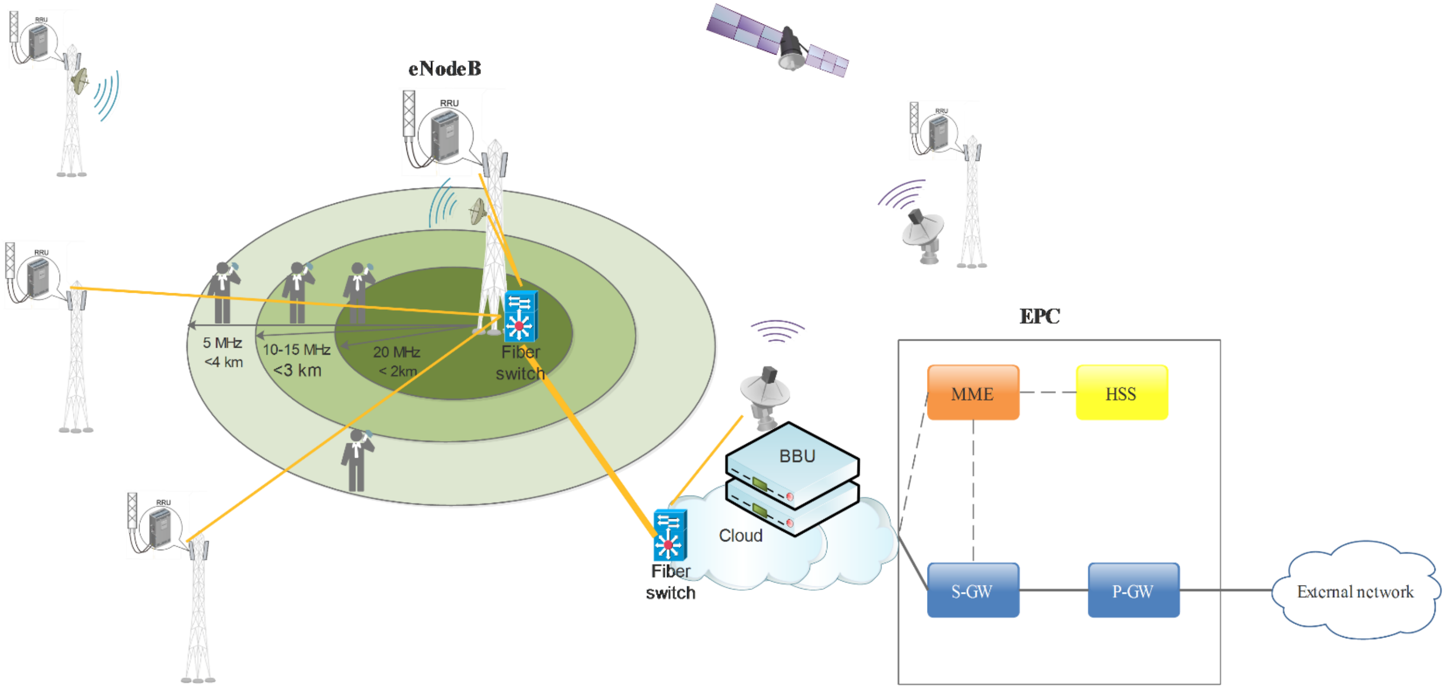
LTE Backhaul Capacity

- Higher bandwidth => shorter distance from RRU => increase in number of eNodeBs
- Increase in number of eNodeBs => require more capacity in backhaul network
- Maximum throughput of each DBS3900 eNB = 450 Mbps
- Each eNB requires at least 4 Gb fiber link to aggregation point for 2×2 MIMO
- Due to short range coverage, existing aggregation links require upgrade



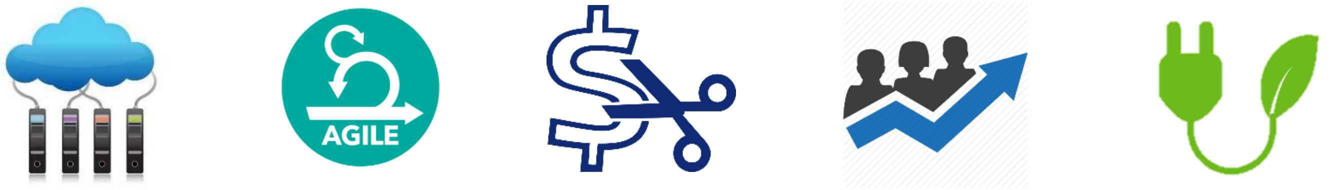
Cloud SDR implementation feasibility

- CPRI links connect RRU to BBU so it can be extended to cloud
- Latency introduced by moving BBU to cloud is small
- Existing backhaul capacity should be upgraded to support cloud SDR.



Cloud SDR Advantages

- ✓ 333.5 watt BBU moves to data center and will consume efficiently
- ✓ BBU hardware change to software license in cloud
- ✓ Deploying new BBU implementation will just be a software upgrade in cloud
- ✓ BBU centralization in cloud facilitate management
- ✓ Operational expenses of eNBs decline
- ✓ Better coordination between operators
- ✓ High processing power
- ✓ Resource pooling



Resource pooling | Agile development | Cost efficiency | Enhance coordination | Energy efficiency

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Thank you