O-RAN

DD

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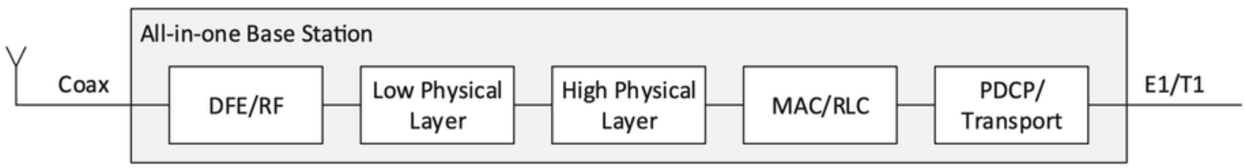
Open-RAN is a set of specifications for RAN created by an industry group called The O-RAN Alliance. Those specifications are not 3GPP or ITU specifications. The alliance started with 5 members: AT&T (USA), Orange (UK), SK Telecom (South Korea), China Mobile, Deutsche Telecom (Germany), NTT DOCOMO (Japan). These telecom companies wanted to impose specifications on RAN equipment vendors, and thus the equipment providers were excluded from the alliance.

Motivation

Pre 5G

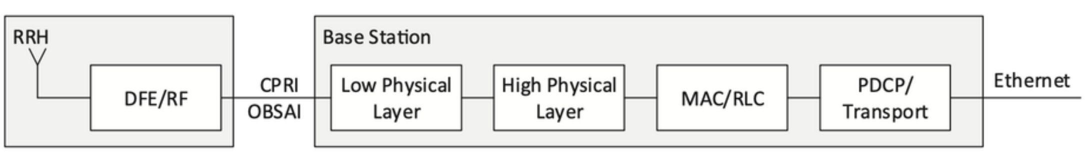
Base stations were originally all in one; they performed all of their operations in the same box located at the base of a tower.



- digital front end (DFE) is the final conditioning of analog voltage as a function of time before transmission, or the first conditioning upon reception.
- the low physical layer includes processing needed to deal with phase shifting between antennas for beam forming, and the fast fourier transform (FFT) in the uplink direction, or its inverse (iFFT) in the downlink direction.
- the high physical layer involves modulation, rate adaption, and in the uplink direction mapping signals to carrier sub-frequencies.
- radio link control (RLC) processes deal with the difference between packets appropriate for transmission via ethernet vs radio through fragmenting, and deals with retransmission for ARQ
- the medium access control (MAC) processes deal with scheduling of packets, concatenation of packets when needed, and with retransmission for HARQ
- packet data convergence protocol (PDCP) deals with robust header compression (RoHC), ordering or packets, and security like encryption (or decryption) just before (or after) transmission from (or to) the base station.

Starting in the early 2000s, vendors started to see the advantages of splitting these functions between two boxes; placing the DFE close to the antenna by placing it high on the radio tower reduced loss since the raw radio signal did not need to travel through as long of a cable before getting conditioned. Thus, the base station was split into a remote radio head (RRH) and (the rest of the) base station with the result of reduced cost because of the removal of the need to have high powered radio frequency coaxial cable running from the top to the base of towers.

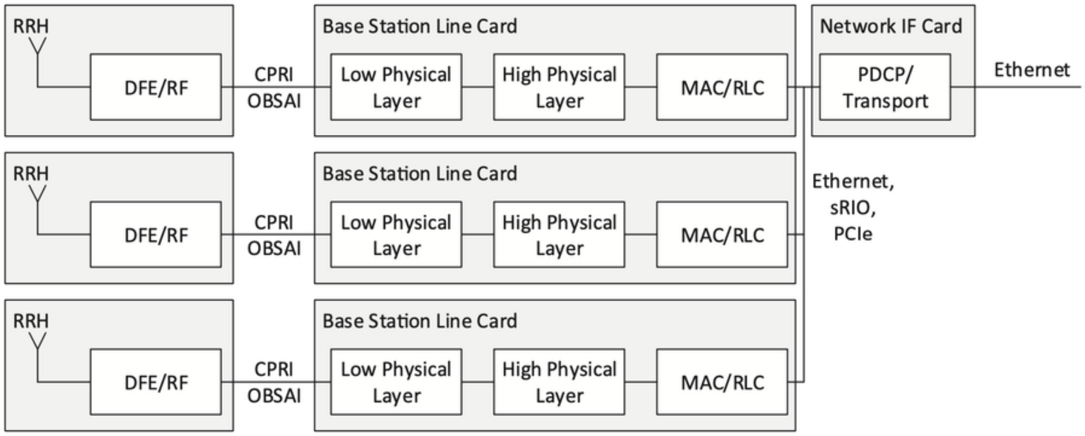
However, to ensure that if you bought a Nokia RRH then you had to buy a Nokia base station, a proprietary system of protocols, cables, and chipsets were developed called open base station architecture initiative (OBASI). Note that the word “open” here was Nokia referring to splitting the base station, but in modern language we would call this setup closed because of its vendor-locked nature.



Base station with remote radio head

Similarly, Ericsson and Huawei used common public radio interface (CPRI) with proprietary "optional features" to lock in mobile network operators.

Later, the ability of one tower to have three (or six) sectors was better matched by peeling of the PDCP functionality into a separate part.



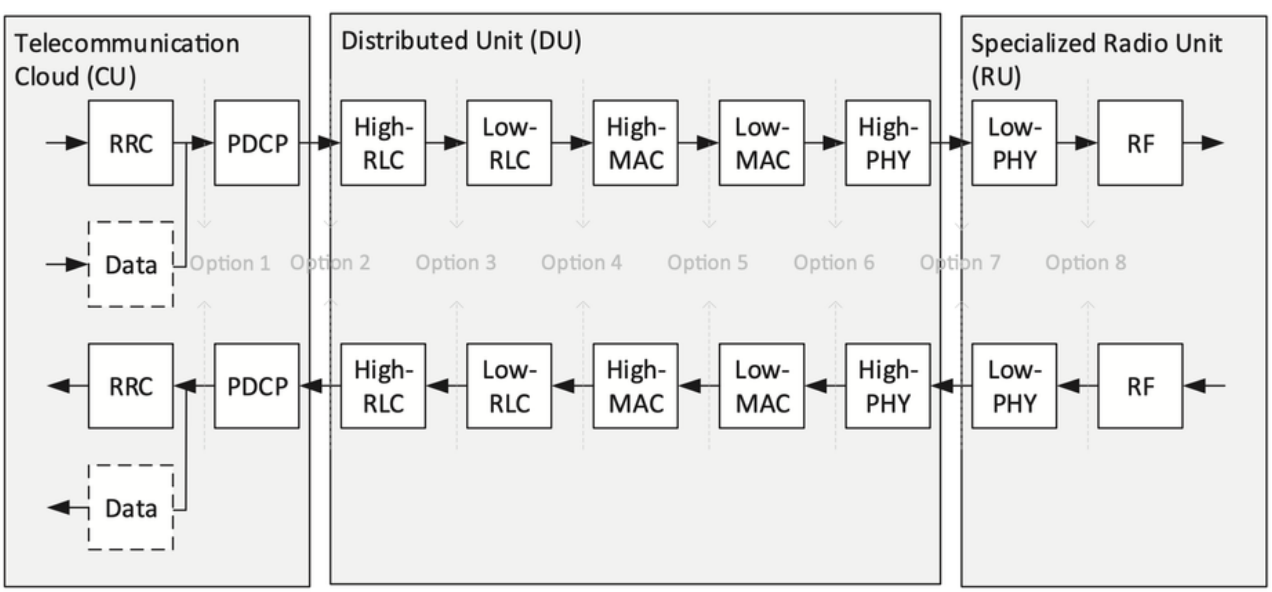
Multi-sector base station with remote radio heads

Again, new interfaces between the parts of the split, the base station line card and network interface card (NIC), were defined: serial rapid IO (sRIO), peripheral component interconnect express (PCIe), asynchronous transfer mode (ATM) et alia; the application programming interface (API) between the base station line card and NIC was vendor locked.

That period of diversification of product and resulting competition led to mergers of companies, resulting in the "famous 5" claiming 95% of the infrastructure market: Nokia, Ericsson, Huawei, Samsung, and ZTE.

5G Needs

The above suggests that there are options for where to split base stations into smaller parts. Term for the parts were developed by 3GPP and O-RAN alliance; RRU, DU and CU.

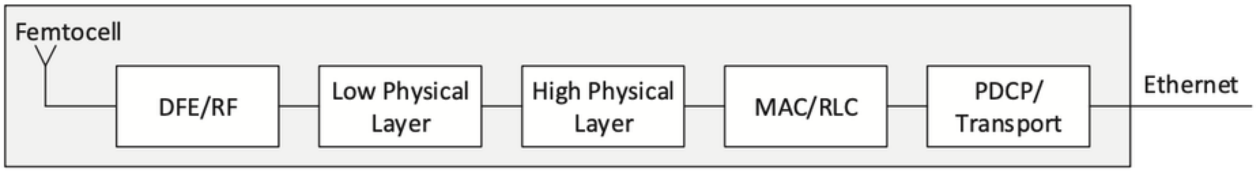


Visualization of one of RU-DU-CU split options

When 5G was being designed, the need for diverse base station architectures was clear. The O-RAN alliance aimed to facilitate each of the following base station types with truly open interfaces between parts. (That is, replace CPRI, OBSAI, sRIO etc with intercase that every hardware vendor must comply with so that parts from different vendors can be swapped out. e.g. a base station line card from Nokia can be swapped out with a base station line card from Ericsson.)

Integrated Small Cells (ISC)

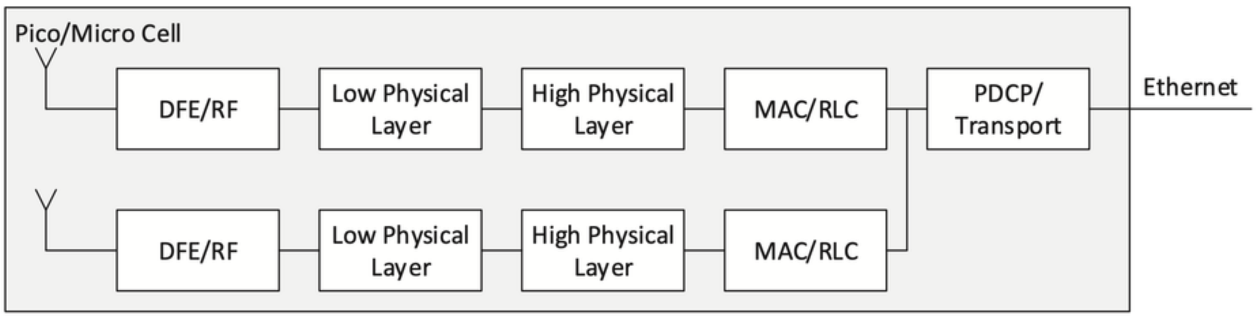
For high bandwidth coverage over small areas the original architecture of an all in one base station, but with all components optimized internally, is perfect.



Optimal femto cell base station

Pico/Micro Cells

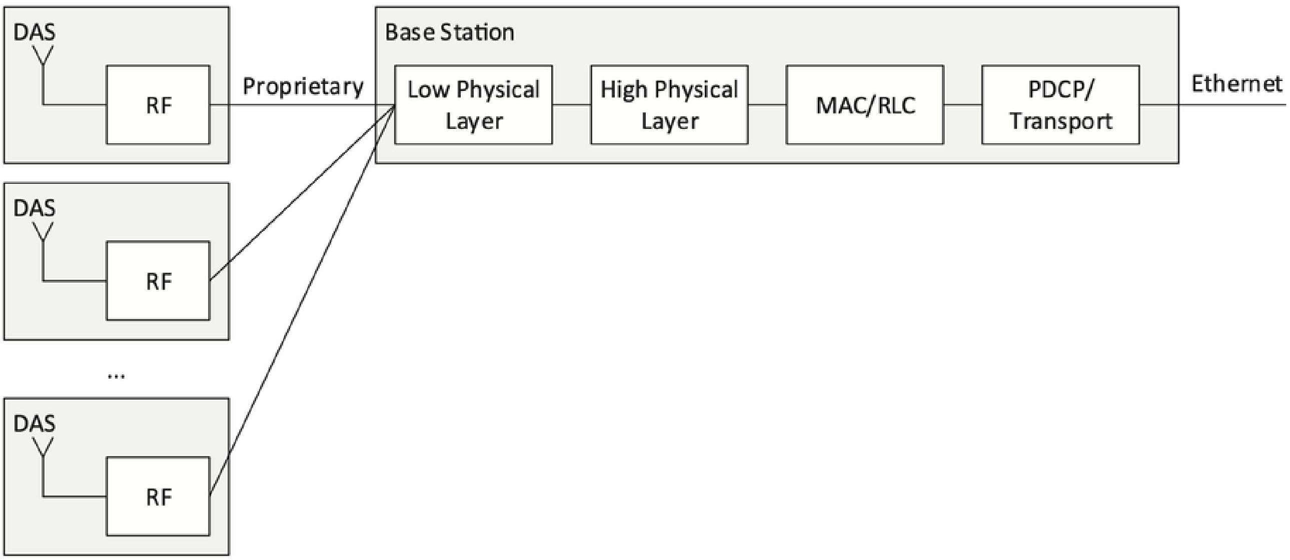
When high bandwidth and multiple antennas are needed, a branched structure will all parts in one box is optimal.



Optimal pico cell base station

Distributed Antenna Systems

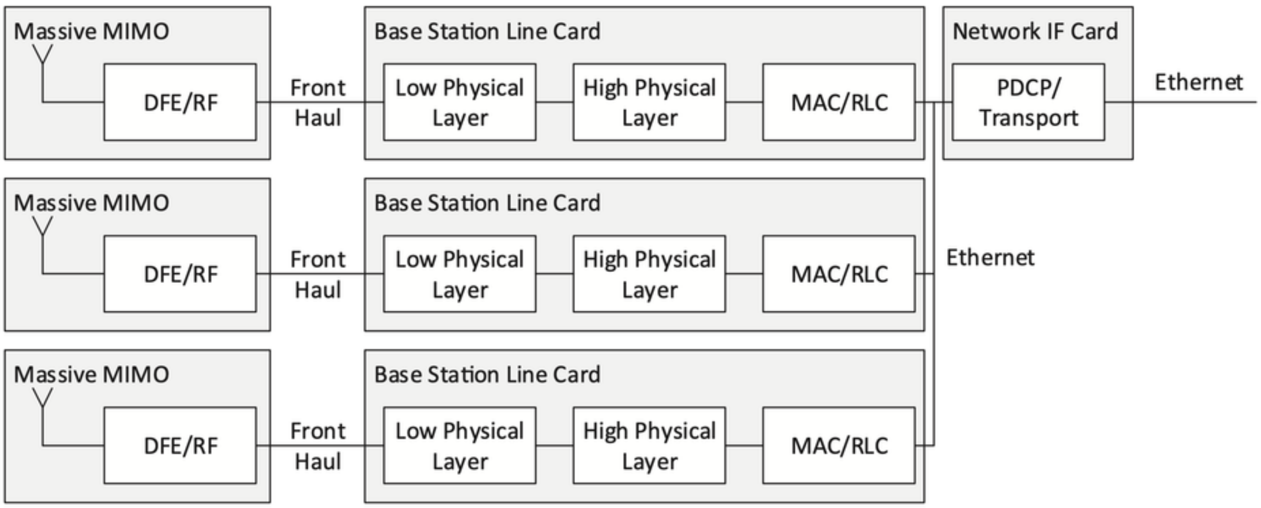
In high demand situations like an arena, shopping mall, casino, or convention center, where many low powered RUs are needed to provide coverage, distributed antenna systems (DAS) are appropriate.



Optimal DAS base station

mMIMO

Massive multiple input multiple output (mMIMO) antennas have heavy compute requirements. Using such antennas in macrocell deployments has lots of advantages in the ability to serve more customers with the same real estate. But the most effective base station structure is the classic multi-sector structure.



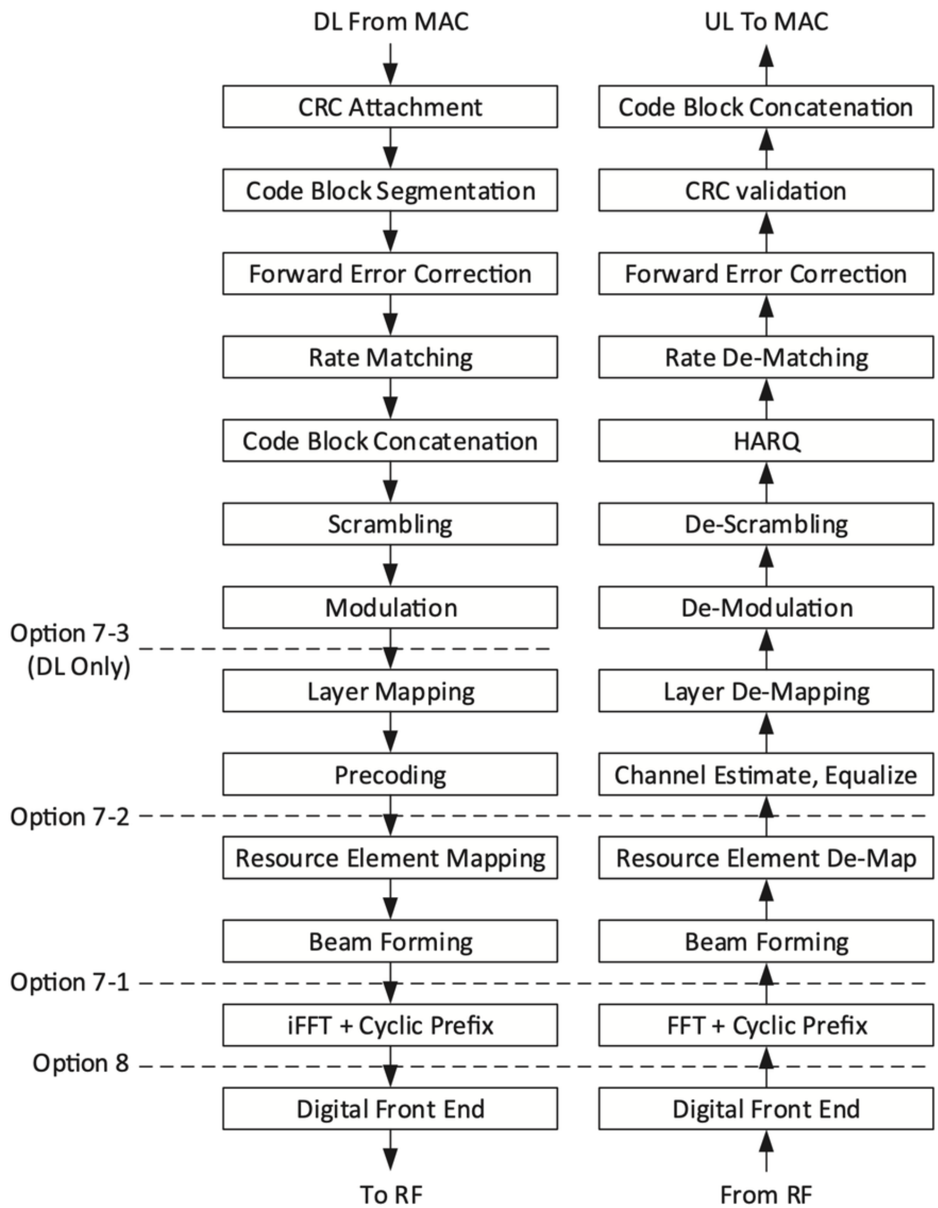
Optimal mMIMO base station

Splitting Options

Zooming in further on the operations performed by a base station, we see that there are many options of where a split can be made between the RRH and base station line card. They are enumerated by O-RAN Alliance. Options 8 and 7 are shown below via dashed lines with the operations below the dashed lines in the RRU, those above in the DU. Option 7 has several variations.

Descriptions of processes

- CRC Attachment (cyclic redundancy check) places a copy of a segment of the bit string from the end at the beginning, allowing some redundancy in the signal that increases transmission fidelity.
- Code Block Segmentation breaks MAC protocol data units (transmission blocks) into smaller code blocks for radio transmission (called code blocks, up to 8448 bits).
- Rate Matching reduces the overhead that comes from channel encoding. The latter increases the number of bits by a factor of about 3 to enable forward error correction.
- Code Block Concatenation orders the code blocks for transmission.
- Scrambling is mapping a sequence of 1s and 0s that might contain a pattern and might be majority 1 or 0 to a sequence that is more likely to be random and is half 1s and half zeros. Scrambled messages are less likely to carry error transmissions; bits carry maximal information when they are from a half 1s half 0s sequence.
- Modulation converts scrambled bits into modulated sinusoidal waves with I/Q values.
- Layer Mapping takes the I/Q values to antenna ports.
- Precoding is a part of beamforming; it splits the stream into one stream per antenna.
- Resource Element Mapping inserts demodulation reference signals (DMRS) that help the receiver decode.
- Beamforming requires adding phase between signals sent to MIMO antennas for beamforming interference.
- iFFT is inverse fourier transform, mapping amplitudes as function of frequency to voltage as a function of time.The cyclic prefix is detected and removed as part of this stage.
- Digital Front End is the final conditioning of analog voltage as a function of time before transmission, or the first conditioning upon reception

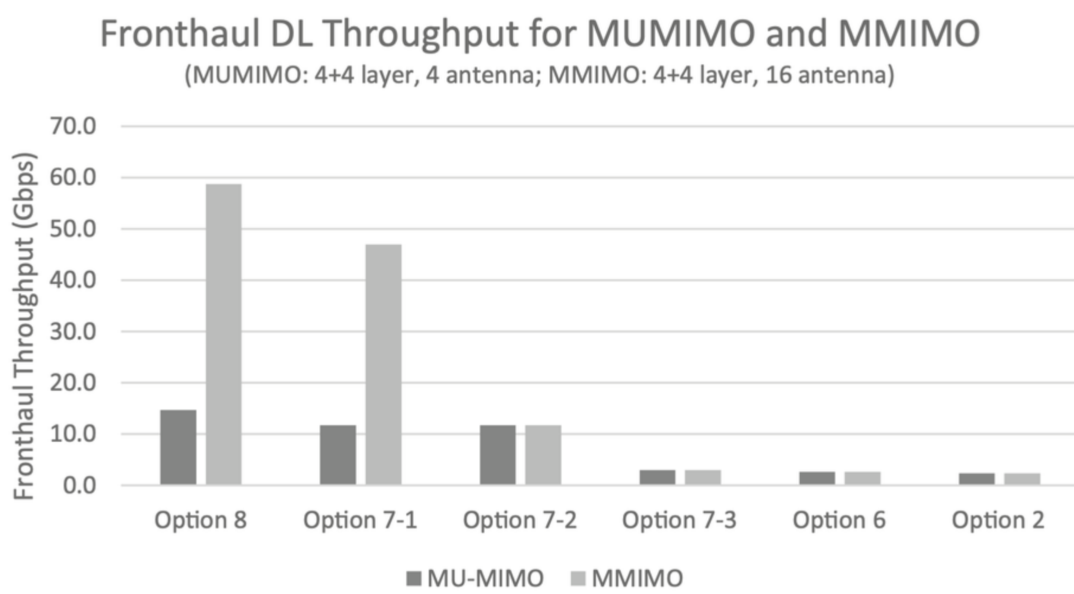


Descriptions of UL processes

- CRC Attachment
- Code Block Segmentation
- Rate Matching
- Code Block Concatenation
- Scrambling is mapping a sequence of 1s and 0s that might contain a pattern and might be majority 1 or 0 to a sequence that is more likely to be random and is half 1s and half zeros. Scrambled messages are less likely to carry error transmissions; bits carry maximal information when they are from a half 1s half 0s sequence.
- Modulation
- Layer Mapping

- Precoding

The fronthaul throughput required changes with the option, since if more processing is done in the radio head then less needs to be transmitted from the radio head. Options 6 through 1 offload even more to the RRH than the options 8 and 7 shown. The following diagram demonstrates reasoning of where to make the split for MIMO.



Option 7-3 is common for MIMO. Another common option for MIMO was developed by a group called xRAN. (The group formed separately but then joined The O-RAN Alliance). This second common split, now called “Option 7-2x category B”, is like 7-2 but puts the precoding (beamforming) on the DU side. (There is also “Option 7-2x category A” which is the same as Option 7-3.)