SoftRAN: Software Defined Radio Access Networks

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RAN Architecture Today

- Macrocell based
- Controller in the packet core/central office
- Dedicated backhaul (fiber) to each macro
  - 1Gbps per site
- Good coverage, but capacity is limited because macrocell deployment cannot be densified further
Densification to scale capacity

- Small cell deployment for spatial reuse and capacity scaling
- Backhaul through a variety of technologies (cable, public fiber, microwave etc)
- Small cells likely on same frequency as macro, in some cases on separate spectrum
Densification: Capacity scaling in practice

Network capacity does not scale because small cells interfere with each other and macro in a dense deployment.
How to densify the RAN and handle interference?

Coordinate small cell radio resource usage to manage interference and increase capacity. Two approaches:

• Distributed SON
  • Power control, eICIC (e.g. Qualcomm UltraSON)

• Centralized baseband and control (CloudRAN)
  • Implement sophisticated interference coordination by processing all packets and signals centrally
Distributed SON

- Each small cell is an independent eNB
- Implements coordination with neighbors via X2
  - X2 is routed over normal backhaul
  - High latency (10ms+)
- Can only implement coarse coordination
  - **Reduce** interference by power control
  - **Avoid** interference by eICIC
Small benefits for edge users, but capacity scaling is still limited because distributed SON only avoids/reduces interference, doesn’t eliminate it.
Approach #2: Cloud RAN

- Each eNB is now only a radiohead (RRH)
- All LTE processing (including L1) is done at a central location
- RRHs backhaul IQ samples from central location via direct fiber
CloudRAN Benefits

- Can implement sophisticated interference coordination mechanisms
  - CoMP or Virtual MIMO to **exploit** interference
  - Power control and eICIC are easily implemented
- Statistical multiplexing helps reduce CAPEX of baseband processing
Distributed MIMO (CoMP-JT) to exploit interference can be implemented with CloudRAN

- Coordinated Multipoint – Joint Transmission (CoMP-JT) tries to **exploit** the interfering links to provide capacity gains
- ICIC, eICIC, and Coordinated Scheduling/Beamforming (CS/CB) try to **avoid** interference
CloudRAN Capacity Scaling

Large capacity gains possible in CloudRAN due to ability to implement sophisticated strategies (e.g. CoMP)
CloudRAN: Impact of Transport Latency

Capacity drops precipitously even when transport latency is as low as 5ms

Source: Qualcomm
Fig 11 in http://www.easy-c.com/publications/p177-brueck.pdf
Achieving 1 millisecond latency is difficult due to buffers even with fiber. Only option is direct fiber with no switches.

Average Latency vs. Advertised Speed - 2012

Source: FCC
Practical, current transport options

• Macro transport is highly engineered, but small cell transport selection based on availability

• “Direct” logical connectivity may include switches and routers in the physical path

• Buffers contribute to latency – not the physical medium

• Too expensive to engineer the network for small cells
CloudRAN: Significant Benefits but Prohibitively Expensive to Deploy

• Significant capacity gains but requires expensive and very high performance transport

• Transport Requirement for CloudRAN
  • Bandwidth: 20Gbps per macro site (16 antennas, 5 bands), 6Gbps per small cell site (4 antennas, 3 bands)
  • Latency: Less 1ms RTT

• Public leased fiber from a third party provider or even multi-gigabit Ethernet is not sufficient, CloudRAN requires direct fiber lines for backhaul
SoftRAN: Bringing (scalable) SDN to the RAN
SoftRAN: Software Defined RAN

SoftRAN provides the benefits of CloudRAN without the enormous transport costs

• Decouples the data plane and control plane for the RAN
• Control plane that programs the radio resource usage in a macro sector in an unified fashion
• Very low latency (<1ms RTT) control transport latency
• Data plane that leverages low cost transport using whatever is available (cable, public fiber etc)
  • Does not require low latency
Interference is local. Macro coverage area natural locality to manage radio resources.

SoftRAN coordinates radio resource management in macro-sector size units

• All microcells and small cells within a macro coverage sector interfere

• Basic unit for intercell interference management
Basestation Stack (eNB)

Data Plane
- Compression
- Handover forwarding
- Ciphering
- Segmentation
- Retransmission
- HARQ
- Antenna & Resource Scheduling
- MCS
- MIMO

Control Plane
- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control

X2 logical interface to neighbor eNBs
SoftRAN: Decoupling eNB Data & Control Planes

Programmable Data Plane
- Compression
- Handover forwarding
- Ciphering
- Segmentation
- Retransmission
- HARQ
- Antenna & Resource Scheduling
- MCS
- MIMO

Controller
- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control

SoftRAN interface
SoftRAN: Decoupling eNB Data & Control Planes

Programmable Data Plane

Programmable Data Plane

Programmable Data Plane

Controller

- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control
- Virtualization Layer

SoftRAN interface
SoftRAN: Controller Abstraction

Radio Resource Abstraction

All eNBs within a macro cluster (within interference region) are treated as one radio resource
- Three dimensional radio resource abstraction
SoftRAN: Controller Applications

• RAN management functions such as load balancing, power control, interference coordination become applications at the SoftRAN controller implemented in an unified manner

• SoftRAN dataplane eNBs are programmed to periodically send network, CSI and flow state records to controller
  • Controller maintains network graph, link quality, CSI and flow demand tables as fast databases

• SoftRAN Controller programs dataplane eNBs to coordinate the use of the shared radio resource and implement functions such as CoMP
SoftRAN: Controller ↔ Data Plane Interface

Interface is match/action, where:

- **Match**: Matches on UE ids, GTP tunnel identifiers and flow identifiers
- **Action**: Is a packet processing pipeline that has to be executed for the matched set of packets
  - Spans PDCP to L1
  - Specifies handover forwarding rules (if any), segmentation parameters, resource block (spectrum) assignments, MIMO streams and the L1 stack to be used for processing the packet
  - Enables precise control over how the radio resource is allocated and used
SoftRAN: Example (CoMP DL JT)

Programmable Data Plane

Match: If Pkt \(\rightarrow\) UE1
Action:
1) Encode using Beamforming vector V1
2) Schedule on RB \(j\) in TTI \(k\)

Match: If Pkt \(\rightarrow\) UE1
Action:
1) Encode using Beamforming vector V2
2) Schedule on RB \(j\) in TTI \(k\)

Controller
- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control
- Virtualization Layer

SoftRAN interface

Programmable Data Plane
SoftRAN: Hybrid, Programmable eNB Data Plane

Controller
- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control
- Virtualization Layer

SoftRAN interface

COTS
- Compression
- Handover forwarding
- Ciphering
- Segmentation

DSP
- Re-TX
- HARQ
- Resource Scheduling
- MCS
- MIMO

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SoftRAN: Physical Architecture

- **Controller (Central Office)**
- **Fiber Backhaul (WDM/IP)**
- **Mobility Control**
  - Security Configuration
  - Flow QoS
  - Load Balancing
  - Scheduling
  - CoMP
  - Power Control
  - Virtualization Layer

- **Microcell**
- **Femtocell**
- **Picocell**
- **Macrocell**

- **Public/Leased IP/Ethernet**
SoftRAN: Transport Architecture
SoftRAN: Transport Requirements

• Dataplane transport at each eNB to the packet core
  • Bandwidth: 150Mbps for small cells and 1Gbps for macro cells (more spectrum & antennas at macro)
  • Latency of around 10-30ms

• Transport between SoftRAN controller and eNBs
  • Bandwidth: 5% of dataplane bandwidth → 7.5Mbps for small cells and 50Mbps for macro
  • Latency: Round trip latency of less than 1 millisecond for both small cells and macros
    • Physical environment varies rapidly, controller needs to react at millisecond timescales for radio resource management
SoftRAN Transport: Physically decouple the control and data plane transport

- Need very low latency control plane transport between eNBs and controller
- Dataplane transport needs high bandwidth backhaul but not very low latency
- SoftRAN’s principle: **Separate the control and data plane transport for RAN**
  - Uniform & separate control plane transport engineered for very low latency
  - Existing high bandwidth but high latency transport for dataplane
SoftRAN Macro Transport

- Macros have highly well-engineered transport
  - Fiber in US, Asia
  - Microwave in EU & others
  - Sufficient bandwidth (1-5Gbps)
  - Low latency (1-5ms) and improving due to newer technology
- SoftRAN doesn’t change macro physical transport, uses the same for control and data
SoftRAN Small Cell Transport: Wireless link between small cell & macro for control transport

Use LTE over the air link between macro cell and small cells within the macro’s coverage area to relay the SoftRAN signals between controller and programmable eNBs

- Lowest possible latency (<1ms RTT)
- Sufficient bandwidth for control (~10Mbps)
- Use whatever backhaul you have access to for data plane without worrying about providing low latency for the control plane
Such Control Plane using direct LTE Wireless link between small cells and macro could not be built because of self-interference at each small cell.
Self-Interference Cancellation (full duplex) for cost-effective low-latency RAN control plane

- **Cost-effective**: Low cost UE modem, straightforward networking
- **Low-latency**: Direct connectivity between radios operating on same frequency (~1ms)
Low Overhead In-Band Control Plane Transport

- Controller transport from the small cells to the macro happens in the same LTE frequencies that the macro is using to serve normal clients.
- Control transmissions are overlaid on top of normal client transmissions → Near zero overhead on the LTE network.
Capacity Scaling with SoftRAN

Capacity wrt Macro baseline with Density

- Current
- Distributed SON
- CloudRAN
- SoftRAN

# of Small Cells per Macro Sector
SoftRAN: Overall Picture

- Mobility Control
- Security Configuration
- Flow QoS
- Load Balancing
- Scheduling
- CoMP
- Power Control
- Virtualization Layer

Controller (Central Office)

Fiber Bkhaul (WDM/IP)

Public/Leased IP/Ethernet

EPC

Control Plane Link
Data Plane Link
SoftRAN Status

• Prototype programmable eNB design completed
• Low latency control transport prototype
  • Bandwidth: ~10Mbps
  • Latency: 800us round trip
• SoftRAN Controller design (ongoing)
  • Interesting SDN controller design challenges around processing latency (microseconds matter)
  • Typical controller design has focused on processing throughput, not latency
  • Need re-design for the RAN
SoftRAN: Conclusion

• Scalable and pragmatic approach to RAN SDN and coordination
• Order of magnitude lower transport requirements compared to CloudRAN with the same capacity benefits
• Evolvable architecture that enables pooling of eNB functions on COTS hardware as transport latency improves
• Provides a central location to add higher layer slicing APIs for new services that need to re-program the RAN