Centralize or Distribute? A Techno-Economic Study to Design Low Cost Edge Cloud Radio Access Network (Appendix)

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I. APPENDIX A

For each split in this work, a single scenario is assumed as a reference. The basic description of the referenced scenario is 1 user per TTI, occupying all PRBs. In this appendix, we provide the detailed definition of referenced scenario:

General parameters:

- 1 user per TTI
- 20MHz channel bandwidth
- 1 carrier component
- UE IP MTU 1500 bytes
- 30.72 MHz sampling rate.

Parameters for Downlink:

- 64 QAM
- 1x1 SISO
- 100 RBs for data (PDSCH)
- MCS 28
- 2 transport blocks of 75376 bits per sub-frame
- CFI = 1
- 1 DCI 2a and 1 DCI 0 (PDCCH)
- 1 HARQ (PHICH)

Parameters for Uplink:

- 16 QAM
- 1x1 SISO
- 96 RBs for data (PUSCH)
- MCS 23
- 1 transport block of 48936 bits per sub-frame
- 4 RBs for control (PUCCH)
- 1 CQI and 1 HARQ received on PUCCH

II. APPENDIX B

Table II PF's Computational Complexity (GOPS) in Reference DU

Complexity of Function	Macro BS	
	Downlink	Uplink
G_1^{ref}	720	560
G_2^{ref}	80	80
G_3^{ref}	30	60
G_4^{ref}	10	20
G_5^{ref}	20	120
G_6^{ref}	200	200

In this appendix, we provide computational complexity of each PF in the referenced scenario. The computational complexity is in Giga Operations per Second (GOPS), which indicates the computational resources needed by the PF. The GOPS values are listed in Table II, which are referred to [1].

III. APPENDIX C

In this appendix, we provide equations for calculating midhaul bandwidth (Mbps) requirement of a given RU-DU pair in downstream and upstream respectively. The materials are referred to Appendix C in [2]. The equations for calculating downstream bandwidth requirement are listed below:

Downstream bandwidth requirement:

$R_1^{Down} = \alpha_1^{Down} \cdot f_s \cdot A$	(1)
$R_2^{Down} = \alpha_2^{Down} \cdot f_s \cdot A$	(2)
$R_3^{Down} = \alpha_3^{Down} \cdot A \cdot n_{PRB}$	(3)
$R_4^{Down} = \alpha_4^{Down} \cdot A \cdot L \cdot n_{PRB} + \beta_4^{Down} \cdot A$	(4)
$R_5^{Down} = \alpha_5^{Down} \cdot L \cdot n_{PRB} + \beta_5^{Down}$	(5)
$R_6^{Down} = \alpha_6^{Down} \cdot L \cdot n_{PRB}$	(6)
$R_7^{Down} = \alpha_7^{Down} L \cdot n_{PRB}$	(7)

f_s is the sampling rate, which scales linearly with the carrier band of DU, namely $f_s = f_s^{ref} \cdot \frac{B}{B^{ref}}$, where $f_s^{ref} = 30.72MHz$. n_{PRB} is the number of physical resource blocks (PRBs), which also scales linearly with the band of DU, namely $n_{PRB} = n_{PRB}^{ref} \cdot \frac{B}{B^{ref}}$, where $n_{PRB}^{ref} = 100$. The equations for calculating coefficients for downstream are listed below:

Downstream coefficients:

$\alpha_1^{Down} = N_{CPRI} \cdot \frac{10}{8}$	(8)
$\alpha_2^{Down} = N_{IQ}$	(9)
$\alpha_3^{Down} = \frac{N_{SC}^{RB} \cdot N_{SYM}^{SUB} \cdot N_{IQ} \cdot 1000}{1000000}$	(10)
$\alpha_4^{Down} = \frac{PDSCH_{REs} \cdot N_{IQ} \cdot 1000}{1000000}$	(11)
$\alpha_5^{Down} = \frac{PDSCH_{REs} \cdot Qm_{PDSCH} \cdot Layers_{DL} \cdot 1000}{1000000}$	(12)
$\alpha_6^{Down} = \frac{IP_{DL}^{TTI} \cdot (IP_{pkt} + Hdr_{PDCP} + Hdr_{RLC} + Hdr_{MAC}) \cdot N_{DL}^{TBS}}{125} + FAPI_{DL}$	(13)
$\alpha_7^{Down} = \frac{IP_{DL}^{TTI} \cdot IP_{pkt} \cdot N_{DL}^{TBS}}{125}$	(14)
$\beta_4^{Down} = \frac{(PCFICH_{REs} + PHICH_{REs} + PDCCH_{REs}) \cdot N_{IQ} \cdot 1000}{1000000}$	(15)
$\beta_5^{Down} = \frac{PCFICH_{REs} \cdot Qm_{PCFICH} + (PHICH_{REs} + PDCCH_{REs} \cdot Qm_{PDCCH})}{1000}$	(16)

Now, we provide equations for calculating upstream bandwidth requirement below:

Upstream bandwidth requirement:

$R_1^{Up} = \alpha_1^{Up} \cdot f_s \cdot A$	(17)
$R_2^{Up} = \alpha_2^{Up} \cdot f_s \cdot A$	(18)

$R_3^{Up} = \alpha_3^{Up} \cdot A \cdot n_{PRB}$	(19)
$R_4^{Up} = \alpha_4^{Up} \cdot \mathrm{A} \cdot L \cdot n_{PRB} - \beta_4^{Up}$	(20)
$R_5^{Up} = \alpha_5^{Up} \cdot L \cdot n_{PRB} - \beta_5^{Up}$	(21)
$R_6^{Up} = \alpha_6^{Up} \cdot L \cdot n_{PRB}$	(22)
$R_7^{Up} = \alpha_7^{Up} \cdot L \cdot n_{PRB}$	(23)

Upstream coefficients:

$\alpha_1^{Up} = N_{CPRI} \cdot \frac{10}{8}$	(24)
$\alpha_2^{Up} = N_{IQ}$	(25)
$\alpha_3^{Up} = \frac{N_{SC}^{RB} \cdot N_{SYM}^{Data} \cdot N_{IQ} \cdot 1000}{1000000}$	(26)
$\alpha_4^{Up} = \frac{N_{SC}^{RB} \cdot N_{SYM}^{Data} \cdot N_{IQ} \cdot 1000}{1000000}$	(27)
$\alpha_5^{Up} = \frac{N_{SC}^{RB} \cdot N_{SYM}^{Data} \cdot Qm_{PUSCH} \cdot Layers_{UL} \cdot N_{SICiter} \cdot N_{LLR}}{1000}$	(28)
$\alpha_6^{Up} = \frac{IP_{UL}^{TTI} \cdot (IP_{pkt} + Hdr_{PDCP} + Hdr_{RLC} + Hdr_{MAC}) \cdot N_{UL}^{TBS}}{125} + FAPI_{UL}$	(29)
$\alpha_7^{Up} = \frac{IP_{UL}^{TTI} \cdot IP_{pkt} \cdot N_{UL}^{TBS}}{125}$	(30)
$\beta_4^{Up} = \frac{N_{SC}^{RB} \cdot N_{SYM}^{Data} \cdot PUCCH_{RBs} \cdot N_{IQ} \cdot N_{IQ} \cdot 1000}{1000000}$	(31)
$\beta_5^{Up} = \frac{PUCCH_{RBs} \cdot N_{SC}^{RB} \cdot N_{SYM}^{Data} \cdot Qm_{PUSCH} \cdot Layers_{UL} \cdot N_{SICiter} \cdot N_{LLR}}{1000}$	(32)

L2/L3 assumptions:

Parameters	Value	Description
Hdr_{PDCP}	2	PDCP header in bytes
Hdr_{RLC}	5	RLC AM header in bytes (estimate per IP packet)
Hdr_{MAC}	2	MAC header in bytes (estimate per IP packet)
IP_{pkt}	1500	IP packet size in bytes
TBS_{DL}	75376	Transport block size (in bits) for downlink
IP_{DL}^{TTI}	$\frac{TBS_{DL}}{(IP_{pkt}+Hdr_{PDCP}+Hdr_{RLC}+Hdr_{MAC})*8}$	DL IP packets per transport block
TBS_{UL}	48936	Transport block size (in bits) for uplink
IP_{UL}^{TTI}	$\frac{TBS_{UL}}{(IP_{pkt}+Hdr_{PDCP}+Hdr_{RLC}+Hdr_{MAC})*8}$	UL IP packets per transport link
N_{DL}^{TBS}	2	DL number TBS per TTI
N_{UL}^{TBS}	1	UL number TBS per TTI
Sched	0.5	Scheduler overhead per UE in Mbps
$FAPI_{DL}$	1.5	DL FAPI overhead per UE in Mbps
$FAPI_{UL}$	1.0	UL FAPI overhead per UE in Mbps

PHY layer assumptions:

Parameters	Value	Description
n_{PRB}	100	Number of physical resource blocks
N_{SYM}^{SUB}	14	Number of symbols per sub-frame
N_{SC}^{RB}	12	Number of subcarriers per PRB
N_{SYM}^{Data}	12	Number of data carrying symbols per sub-frame
Qm_{PDSCH}	6	64 QAM modulation used for PDSCH
Qm_{PUSCH}	4	16 QAM modulation used for PUSCH
Qm_{PCFICH}	2	QPSK modulation used for PCFICH
Qm_{PDCCH}	2	QPSK modulation used for PDCCH
$Layers_{DL}$	2	Number of DL layers
$Layers_{UL}$	1	Number of UL layers
$PDSCH_{REs}$	150	PDSCH Resource Element per PRB
$PCFICH_{REs}$	16	Number of Res for PCFICH
$PHICH_{REs}$	12	One PHICH group
$PDCCH_{REs}$	144	Aggregation level 4
N_{IQ}	32	16I + 16Q bits
$PUCCH_{RB}$	2	Number of RBs allocated for PUCCH
N_{LLR}	8	8-bit LLRs
$N_{SICiter}$	1	No SIC
N_{CPRI}	32	15I + 15Q bits
f_s	30.72Mbps	Sampling Rate at 20 MHz

REFERENCES

[1] C. Desset, et al. "Flexible power modeling of LTE base stations." 2012 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2012.

[2] Small Cell Forum, "Functional splits and use cases for small cell virtualization." Jan. 2016.