Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Enhancement to 802.15.4-2006 for hybrid contention access and scheduled access]
Date Submitted: [03 July, 2008]
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Re: [IEEE P802.15.4e Call For proposal]

Abstract: [This document proposes an enhancement to IEEE 802.15.4-2006 MAC Layer for the Reliability and Deterministic Aware Applications, which needs hybrid contention access and scheduled access]

Purpose: [This document is a response to Item a) better support the industrial markets in IEEE P802.15.SG4e Call for Application on 14 November, 2007]

Enhancement to 802.15.4-2006 for hybrid contention access and scheduled access

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10 June 2008

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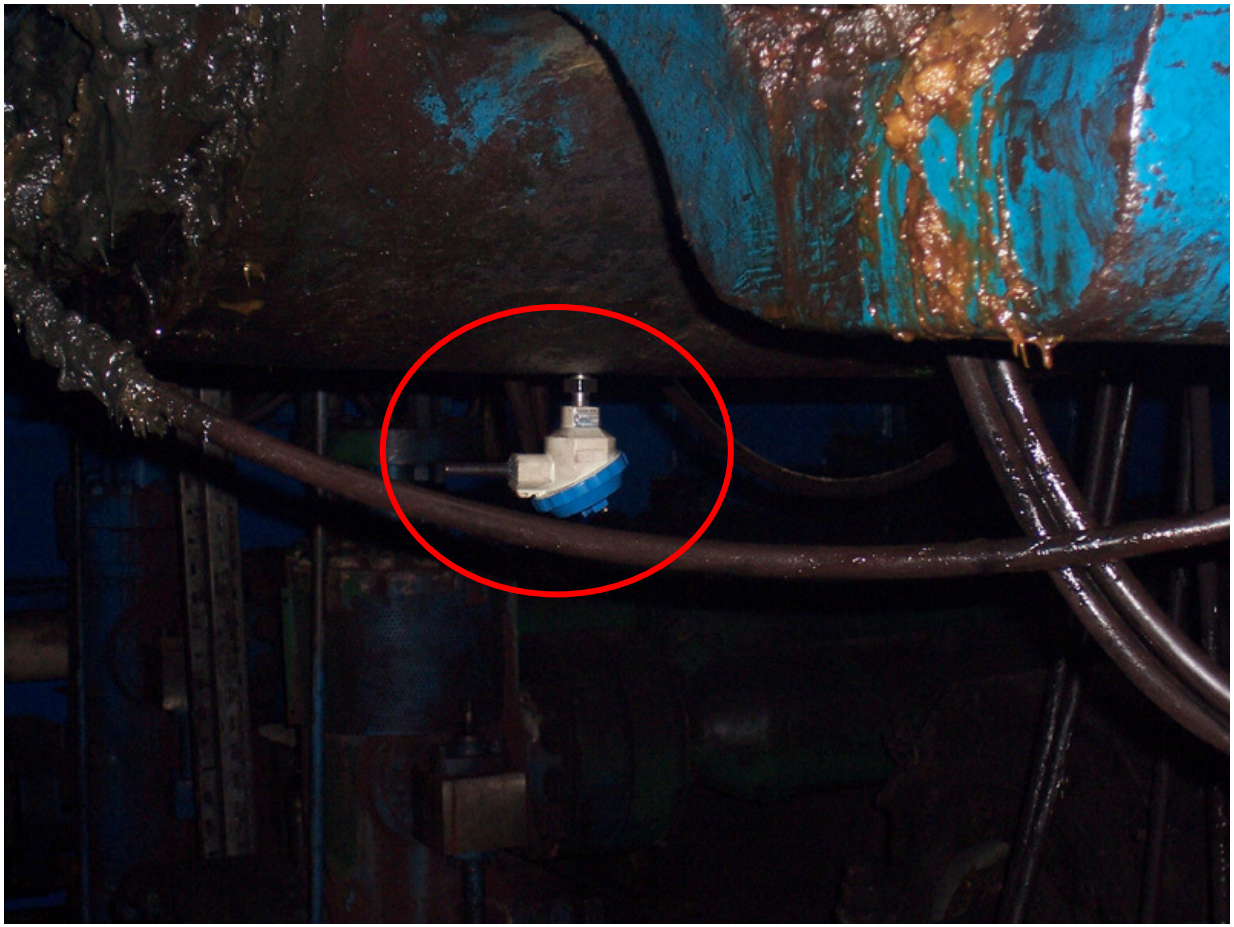
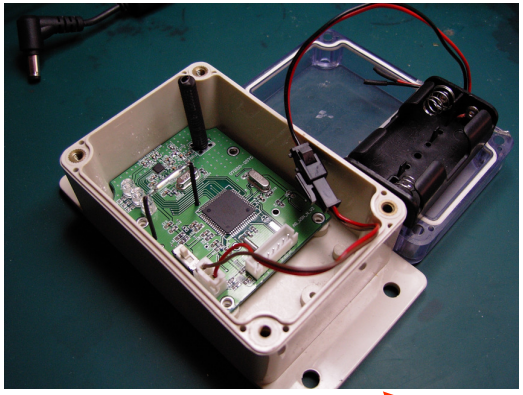
Application Requirements and Constraints

- Large scale
- High Reliability requirement
- Fast communication for emergency information and very low duty cycle communication for regular information.

Application Requirements and Constraints



Application Requirements and Constraints (cont.)



- Placement constraints
- Lifetime constraints

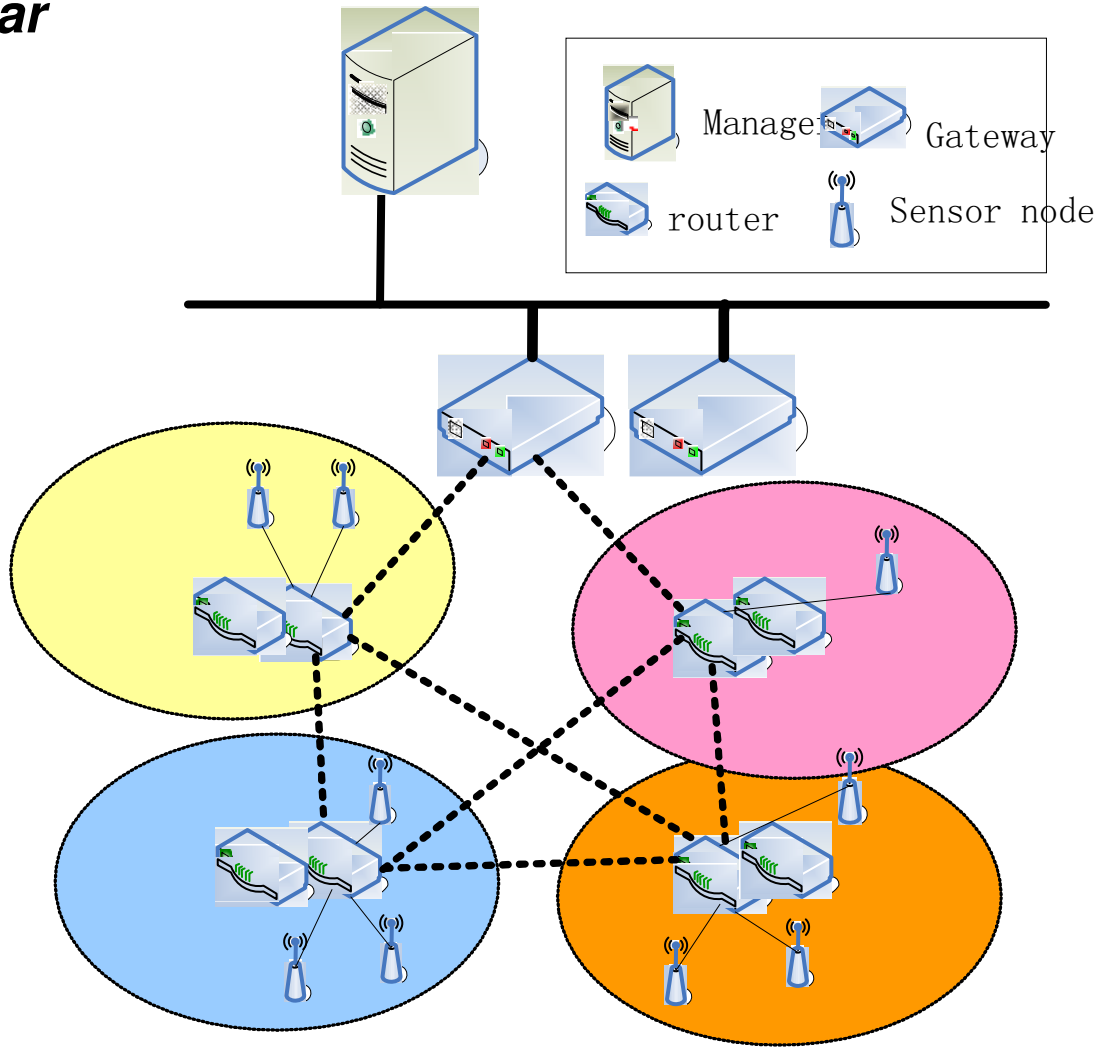
Objective

1. Increase reliability
2. Increase deterministic degree of end-to-end communication
3. Balance the fast communication for emergency information and the very low duty cycle communication for regular information
4. Compatible with IEEE 802.15.4-2006 device

Components.

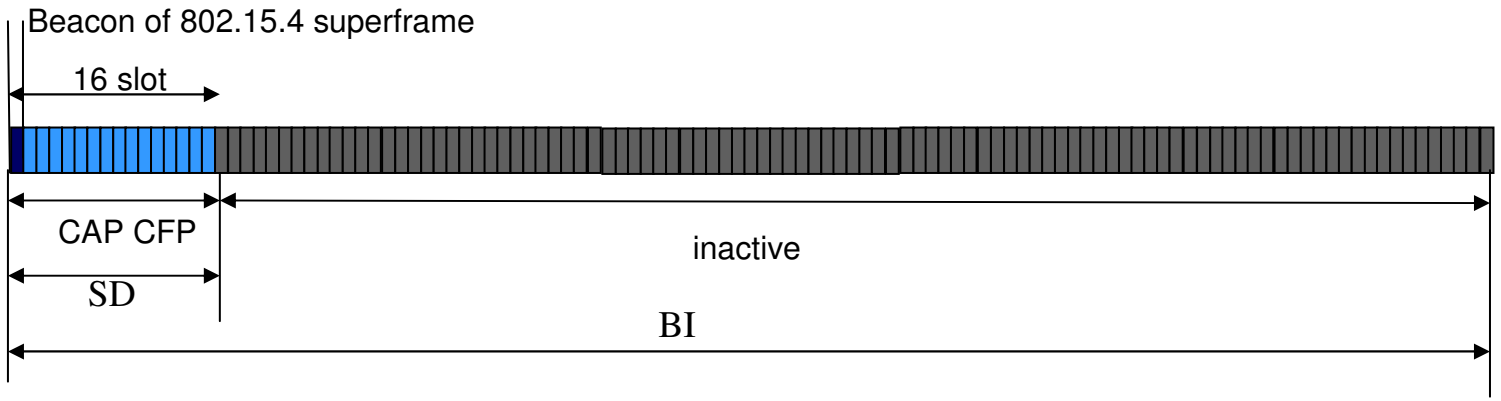
1. Mesh+Star topology
2. Extended superframe
3. CSMA/TDMA+FDMA during CAP+CFP period
4. TDMA+FH/AFD during scheduled period, i.e. inactive period of 15.4-2006
5. Two-stage resource allocation

Network topology
-- Mesh + Star

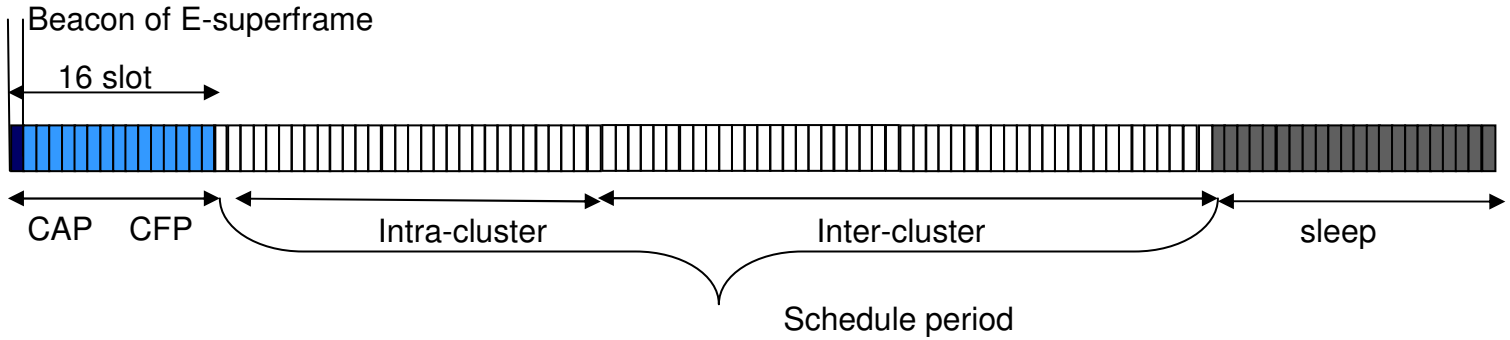


E-Superframe

IEEE802.15.4 Superframe



E-Superframe



E-Superframe(cont)

- CAP is used for device joining, intra-cluster management and retry.
- CFP is used for emergency data and communication between router and intra-cluster mobile devices.
- Intra-cluster is used by intra-cluster fixed devices.
- Inter-cluster is used for communication between routers or outer and gateway.

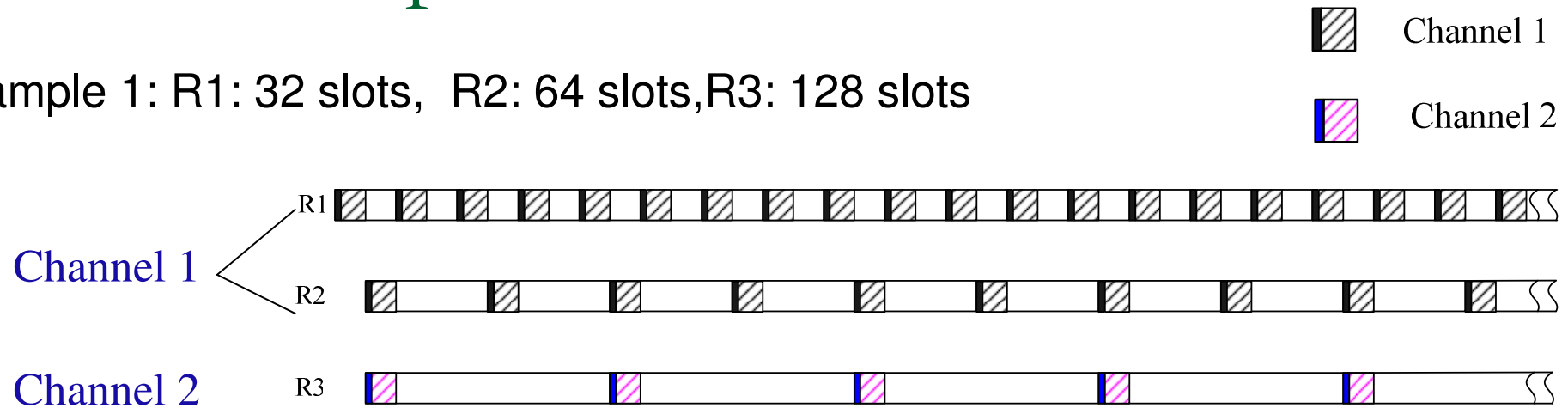
CAP+CFP: CSMA/TDMA+FDMA

- In CAP+CFP period of one superframe cycle, all devices in a cluster use the same channel, which can be modified in another cycle by forecast of beacon.

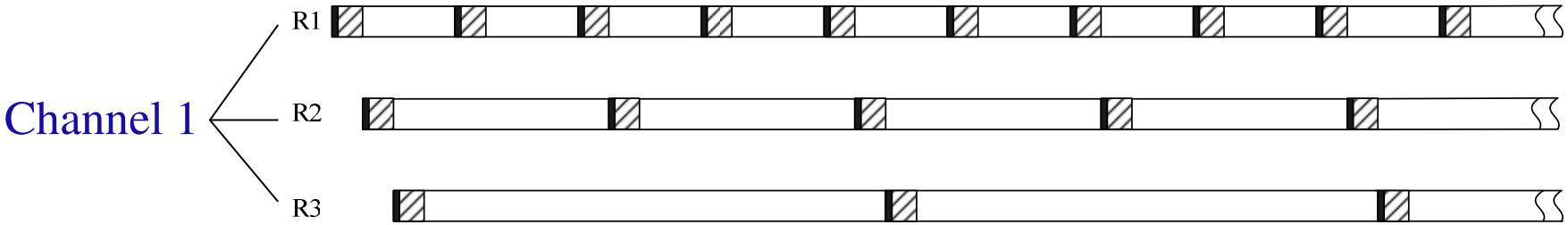
- Neighbor routers are assigned with different working channels.
  - If there is no enough channel, CAP+CFP period of neighbor routers should be scheduled to be staggered.

Two examples of CAP+CFP

Example 1: R1: 32 slots, R2: 64 slots,R3: 128 slots



Example 2: R1: 64 slots, R2: 128 slots, R3: 256 slots



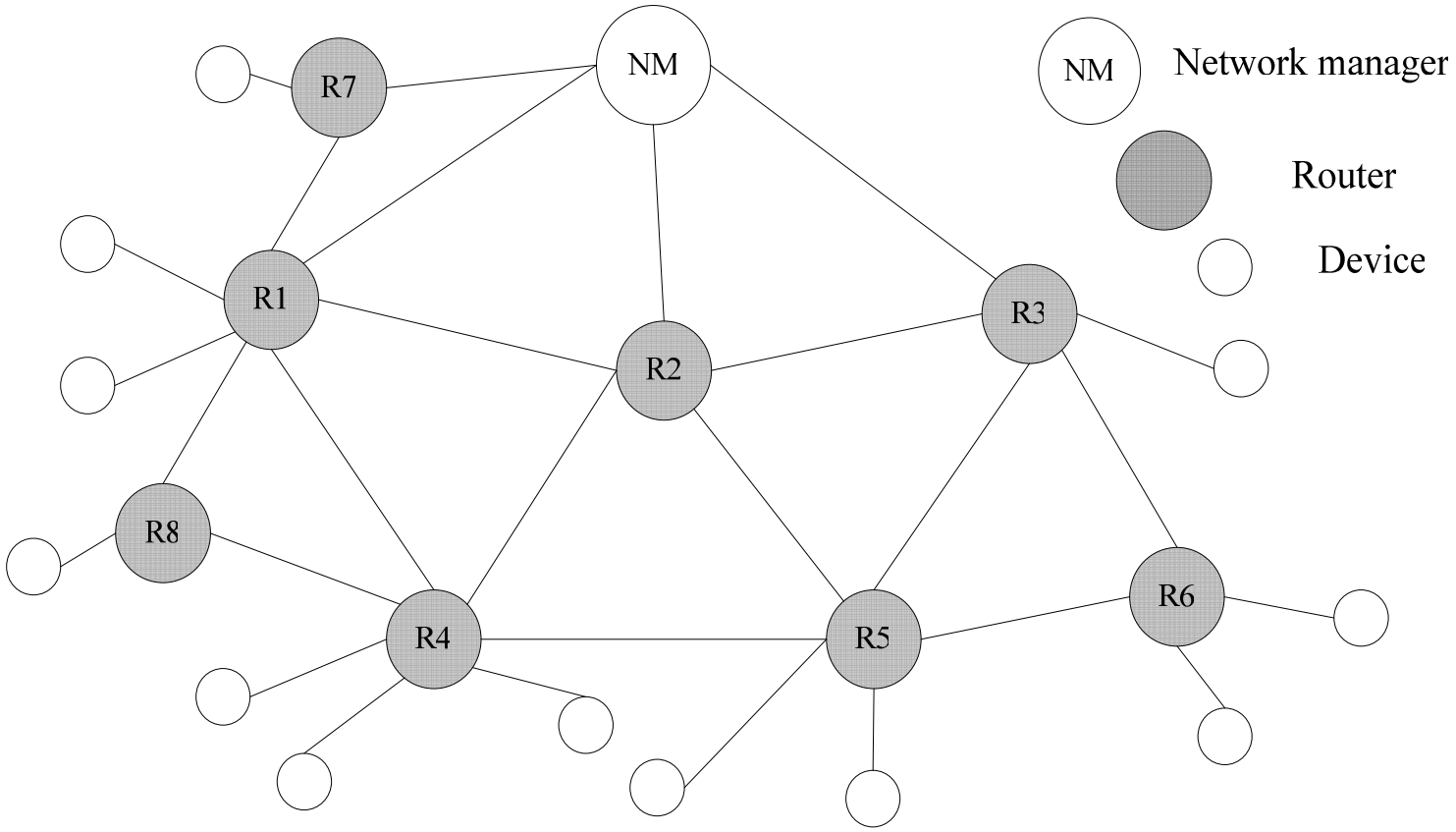
Intra-cluster and Inter-cluster

- **TDMA+FH/AFD**
- FH: Change communication channel according to a scheduled frequency hopping pattern, regardless how the real channel condition is.
- AFD: Change communication channel according to the real channel condition. In another word, bad channel condition, which can be measured with packet drop rate or resend time, triggers the operation of changing channel.

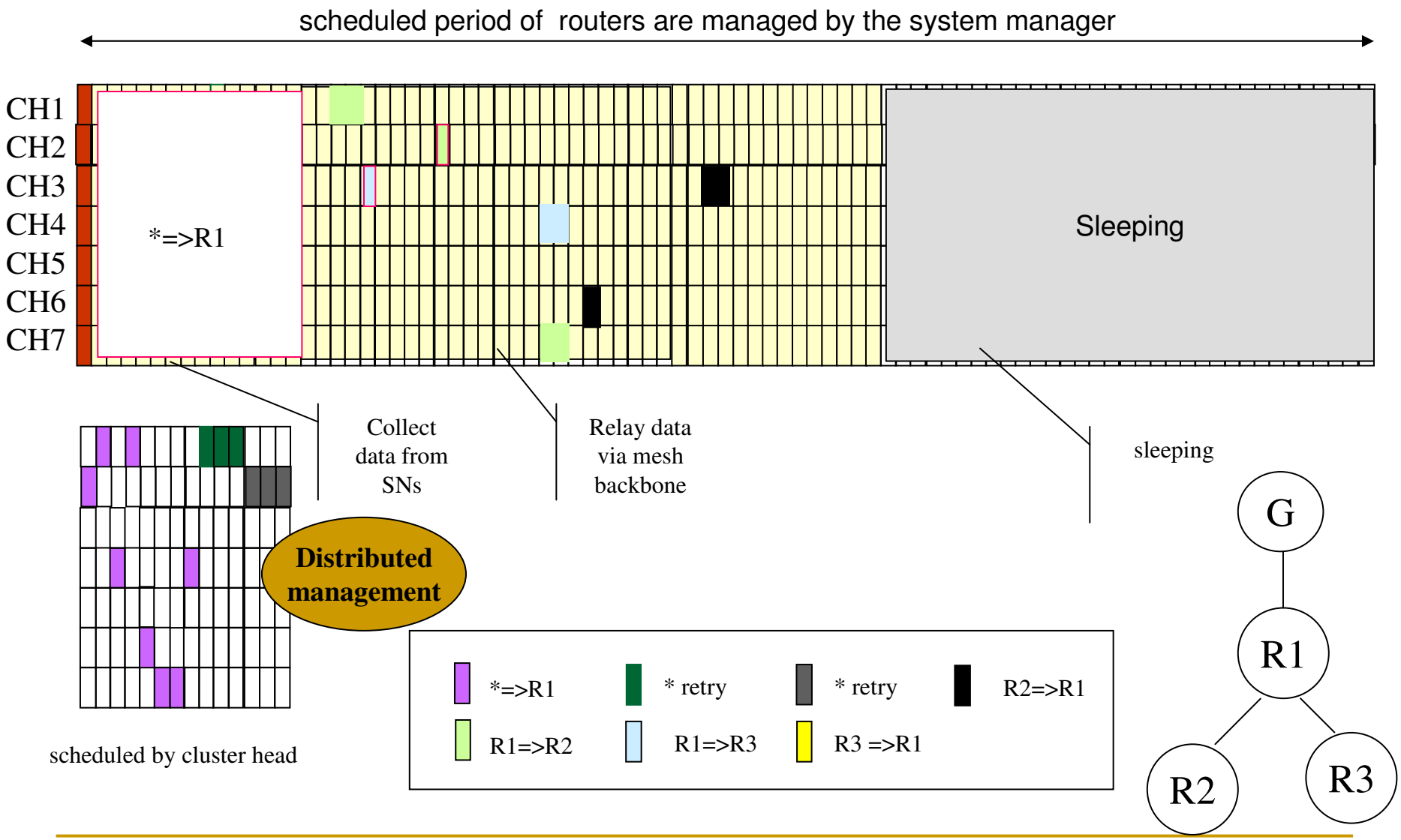
Two-stage Management: timeslot, channel vs. link

- *Inter-cluster period is scheduled by network manager*
- *CFP and Intra-cluster is scheduled by router.*

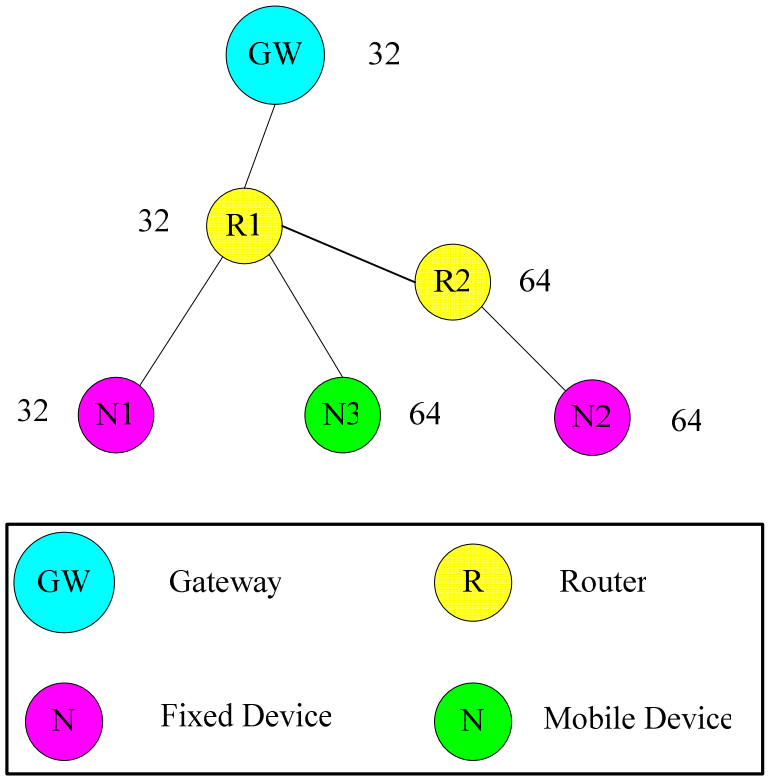
Distributed Resource Allocation



Two-stage Management: timeslot, channel vs. link



An example of Device Joining and Resource Allocation



Join Sequence:

- GW ->R1->N1->R2->N2->N3

Data communication path:

- N1->R1->GW
- N3->R1->GW
- N2->R2->R1->GW

Data Update Rate

- Router data update rate =

  min update_rate(device1, device 2,…, device n);

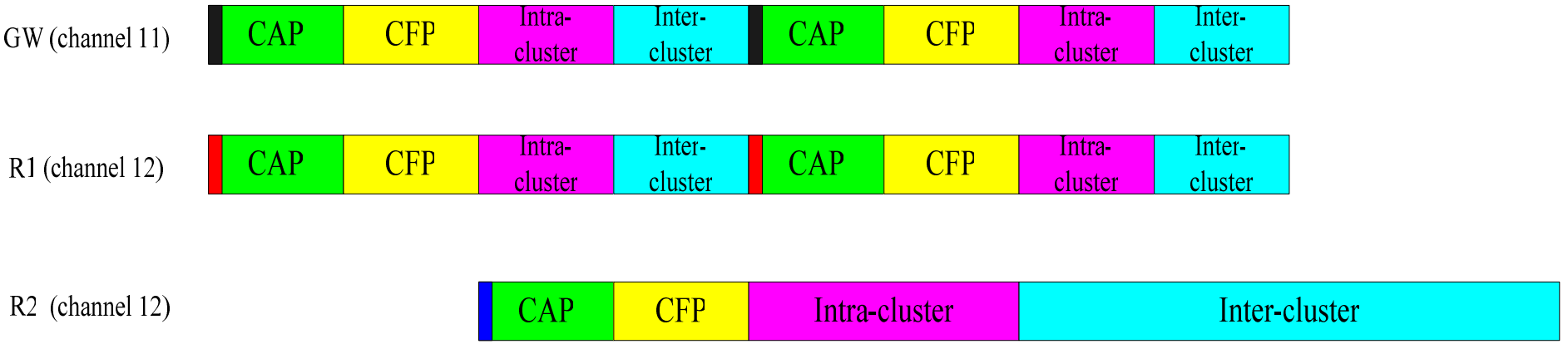
- GW data update rate is defined as the minimum data update rates of network.

Device	Data Update Rate (slots)
N1	32
N2	64
N3	64
R1	32
R2	64
GW	32

Default Superframe -64 slots

Period	Length (slots)
Beacon	1
CAP	7
CFP	8
Intra-cluster	16
Inter-cluster	32

Final Superframe Length and Channel

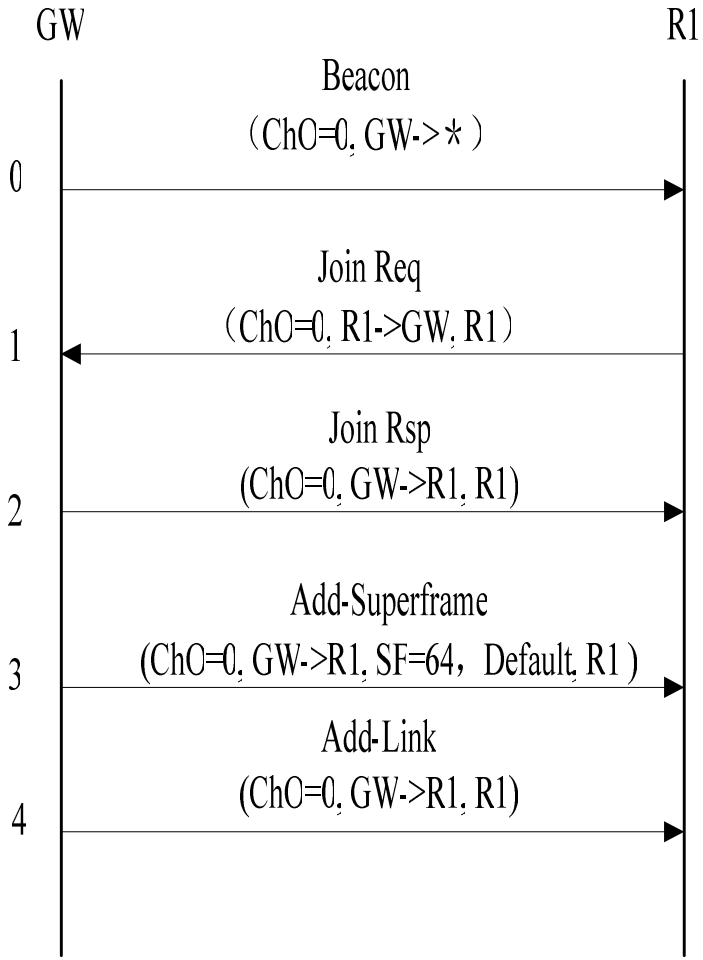


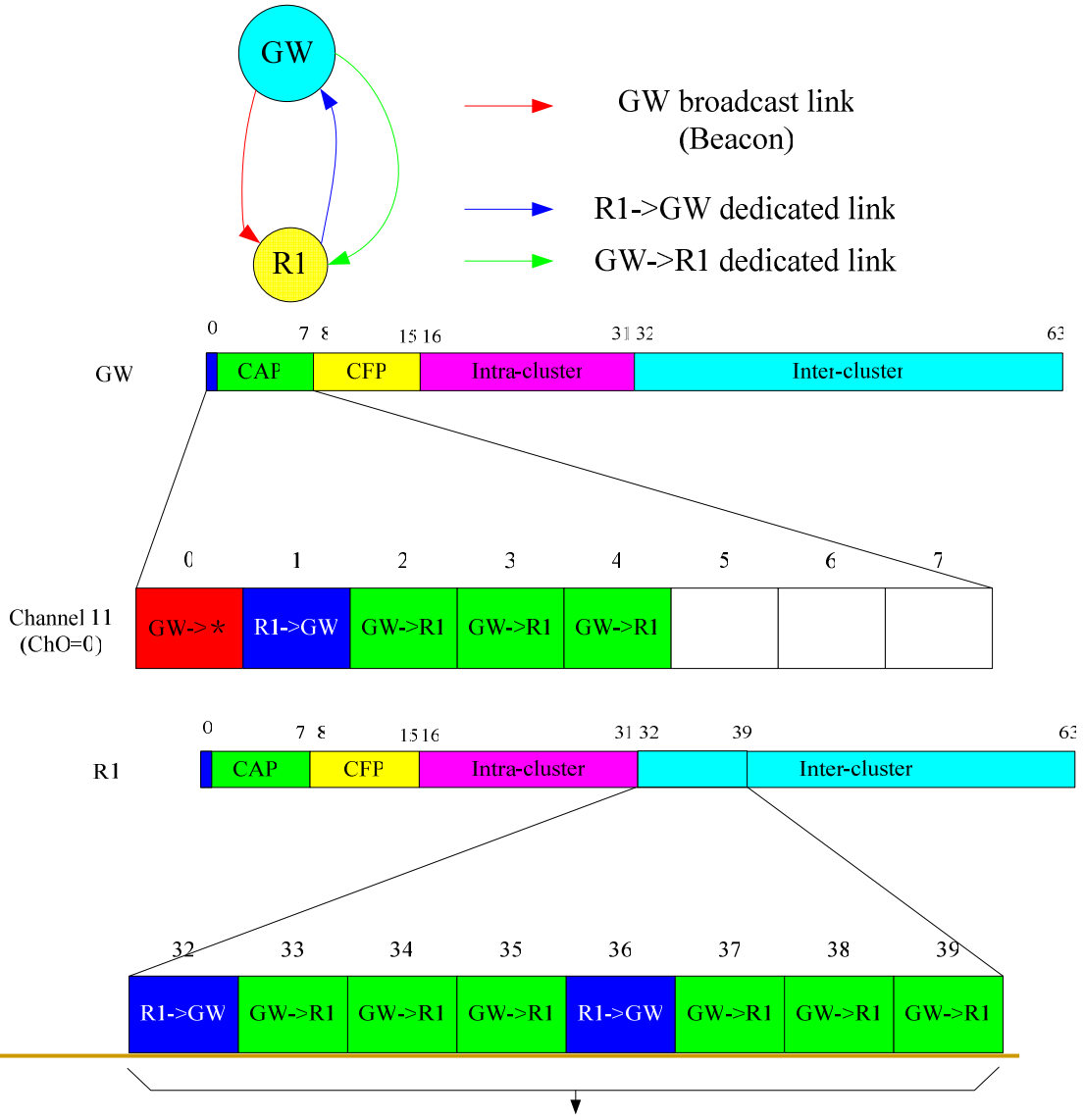
	Superframe length	Channel	Slot Offset
GW	32	11	0
R1	32	12	0
R2	64	12	16

Final Superframe Structure

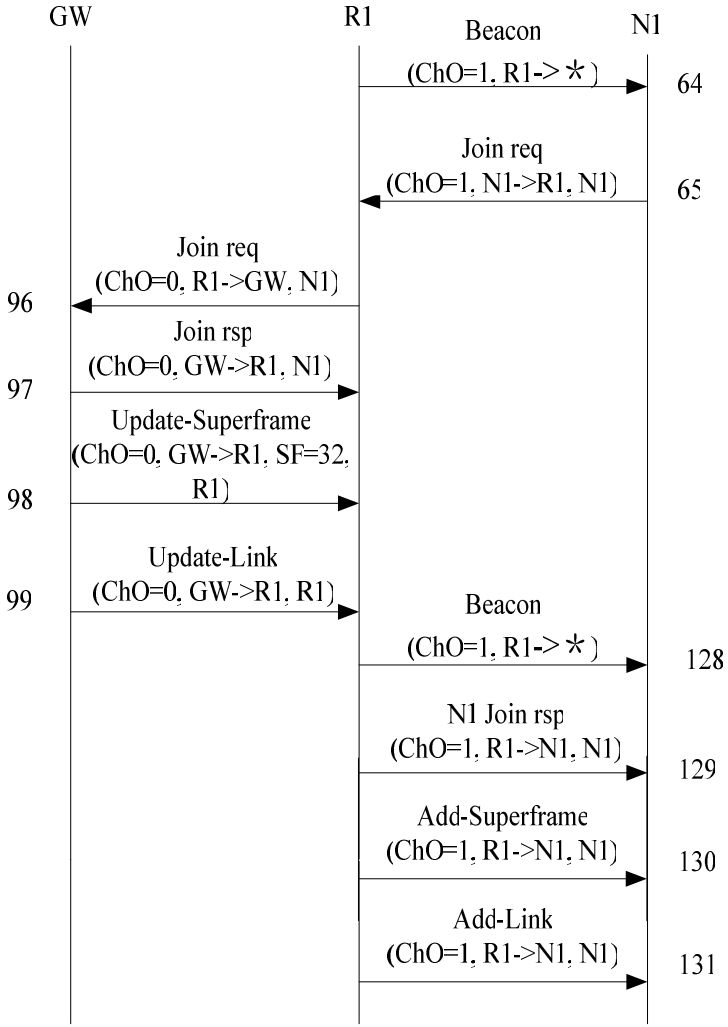
	Beacon	CAP	CFP	Intra-cluster	Inter-cluster
GW	1	7	8	8	8
R1	1	7	8	8	8
R2	1	7	8	16	32

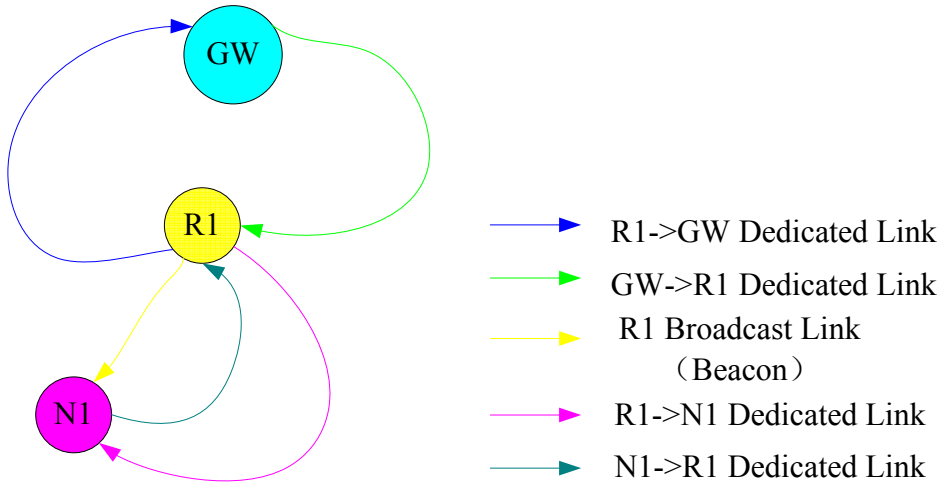
Joining Process of R1

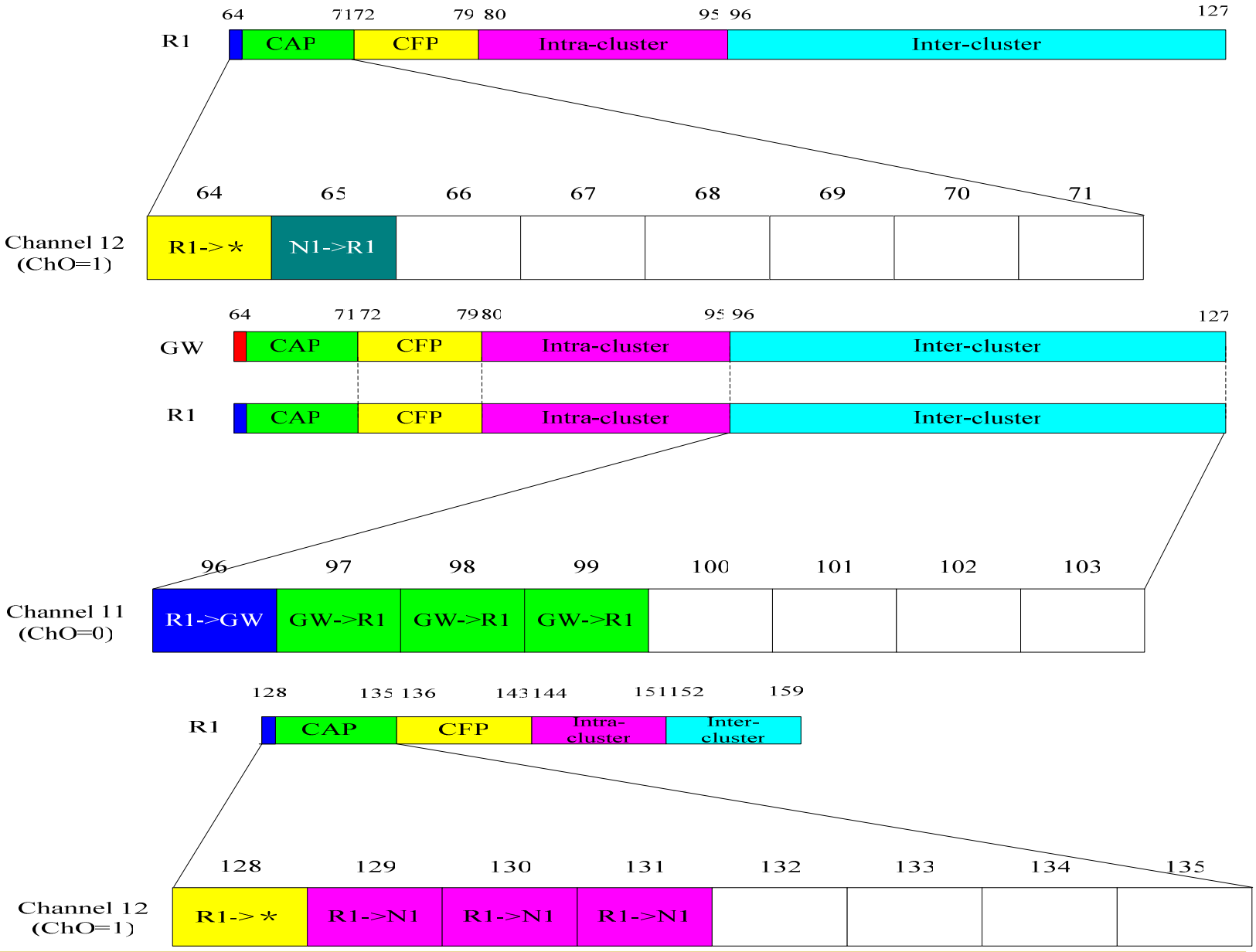




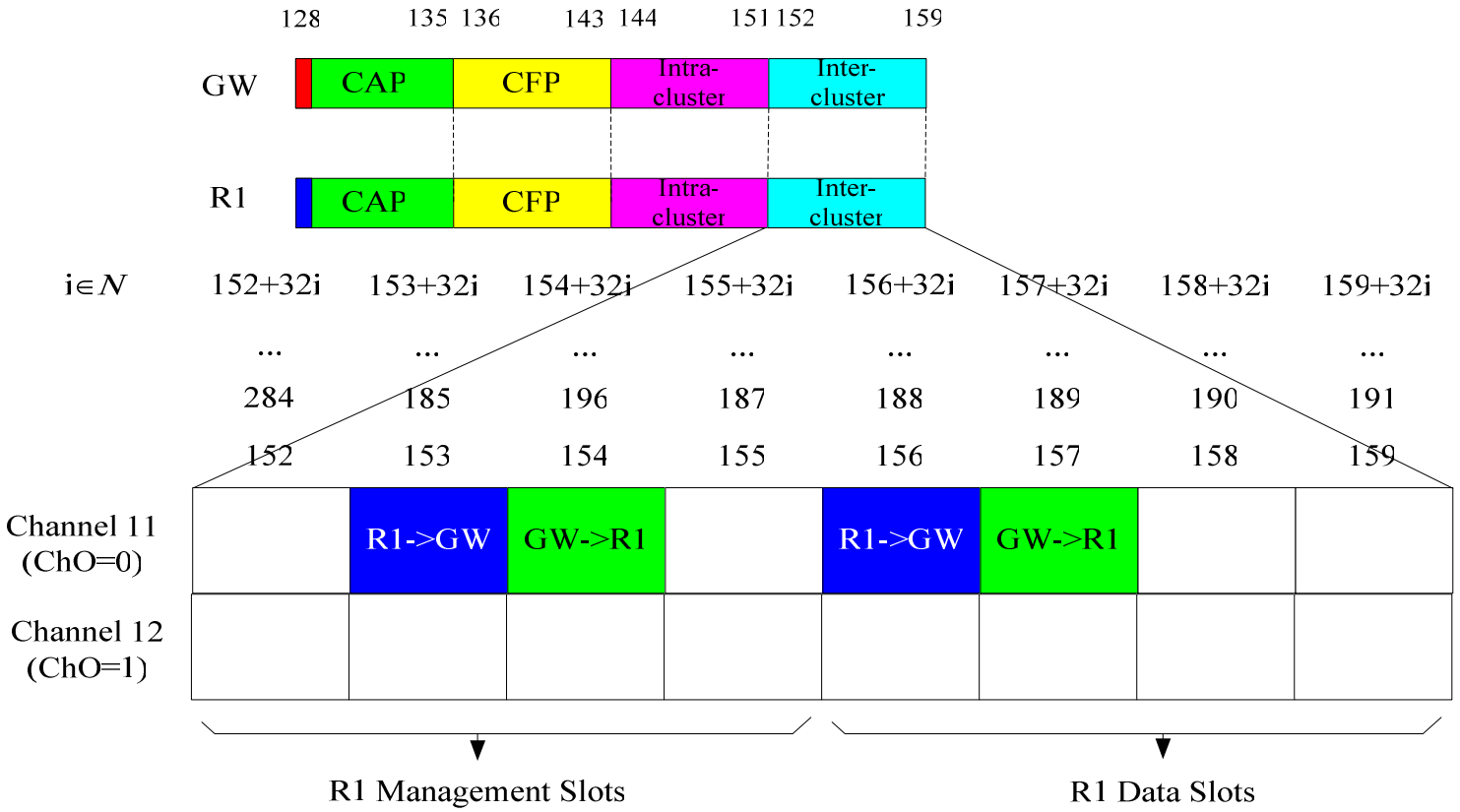
Joining and resource allocation of N1



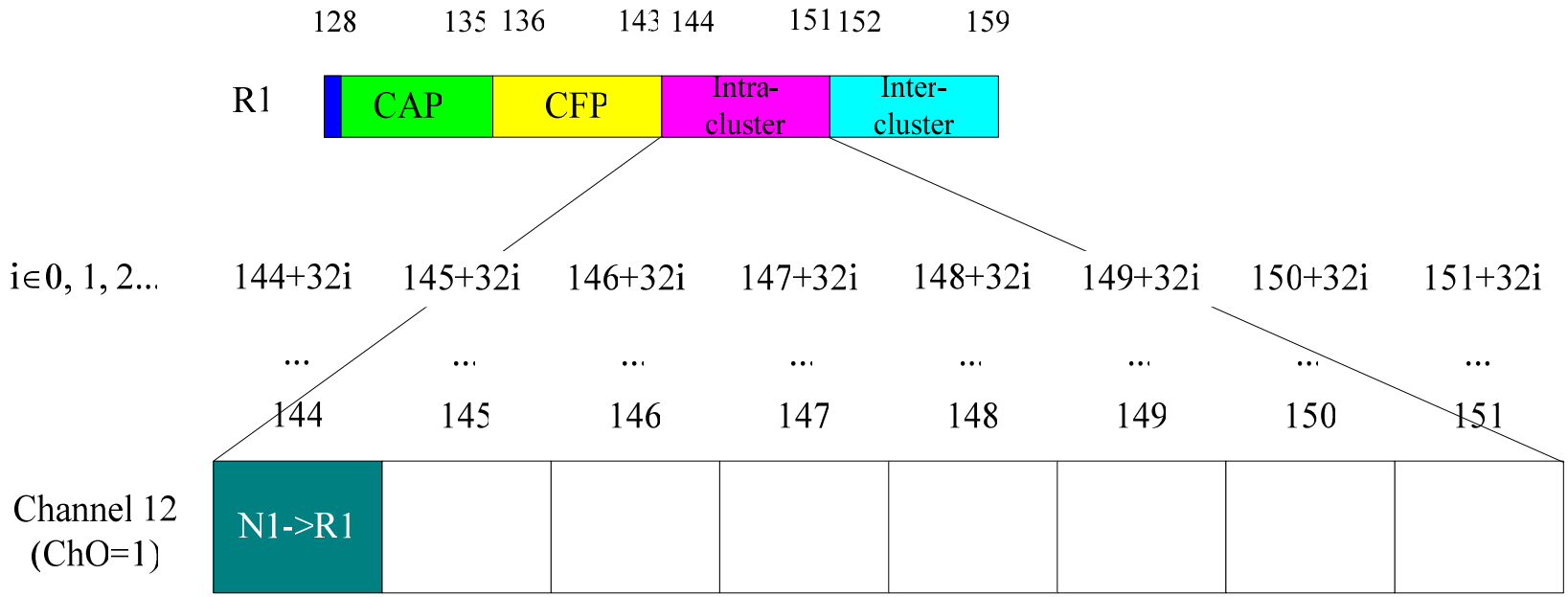



64
7172
79 80
95 96
127
R1
CAP
CFP
Intra-cluster
Inter-cluster
64
65
66
67
68
69
70
71
Channel 12
(ChO=1)
R1->*
N1->R1
64
71 72
79 80
95 96
127
GW
CAP
CFP
Intra-cluster
Inter-cluster
R1
CAP
CFP
Intra-cluster
Inter-cluster
96
97
98
99
100
101
102
103
Channel 11
(ChO=0)
R1->GW
GW->R1
GW->R1
GW->R1
128
135 136
143 144
151 152
159
R1
CAP
CFP
Intra-cluster
Inter-cluster
128
129
130
131
132
133
134
135
Channel 12
(ChO=1)
R1->*
R1->N1
R1->N1
R1->N1

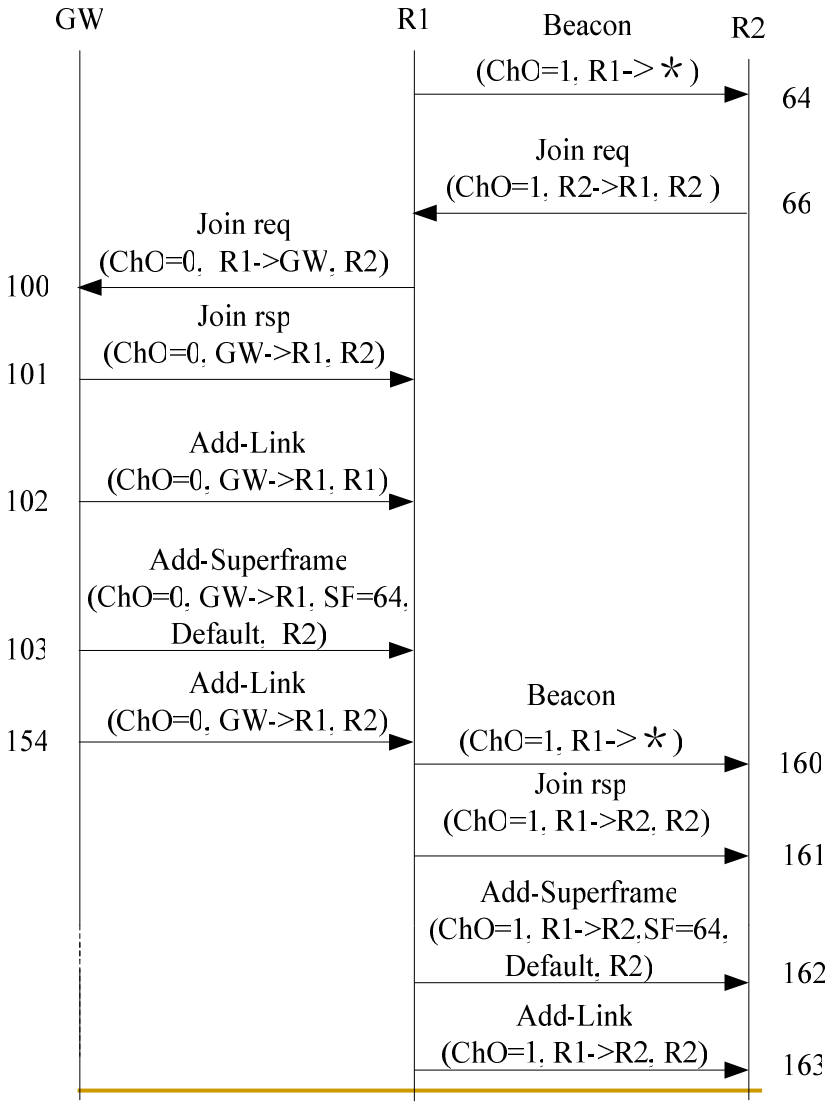
- After GW receiving N1's joining request, GW updates R1's superframe, and allocates data slots to R1.

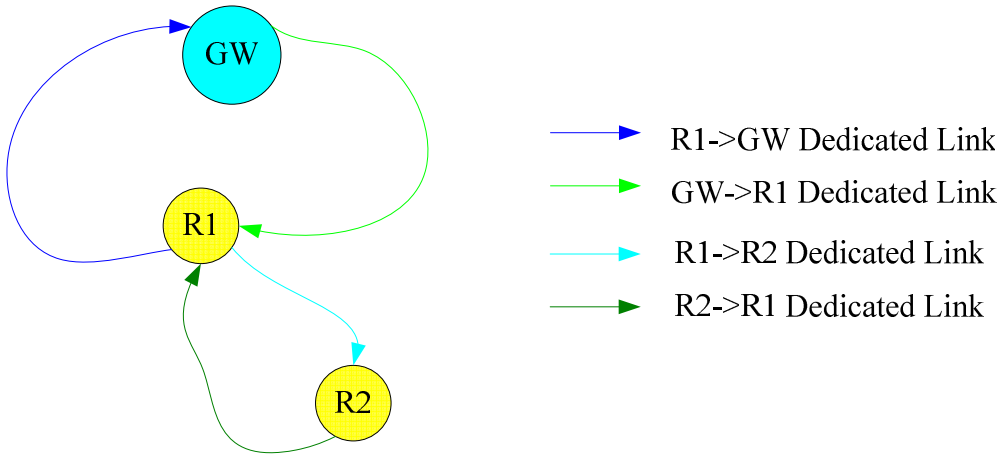


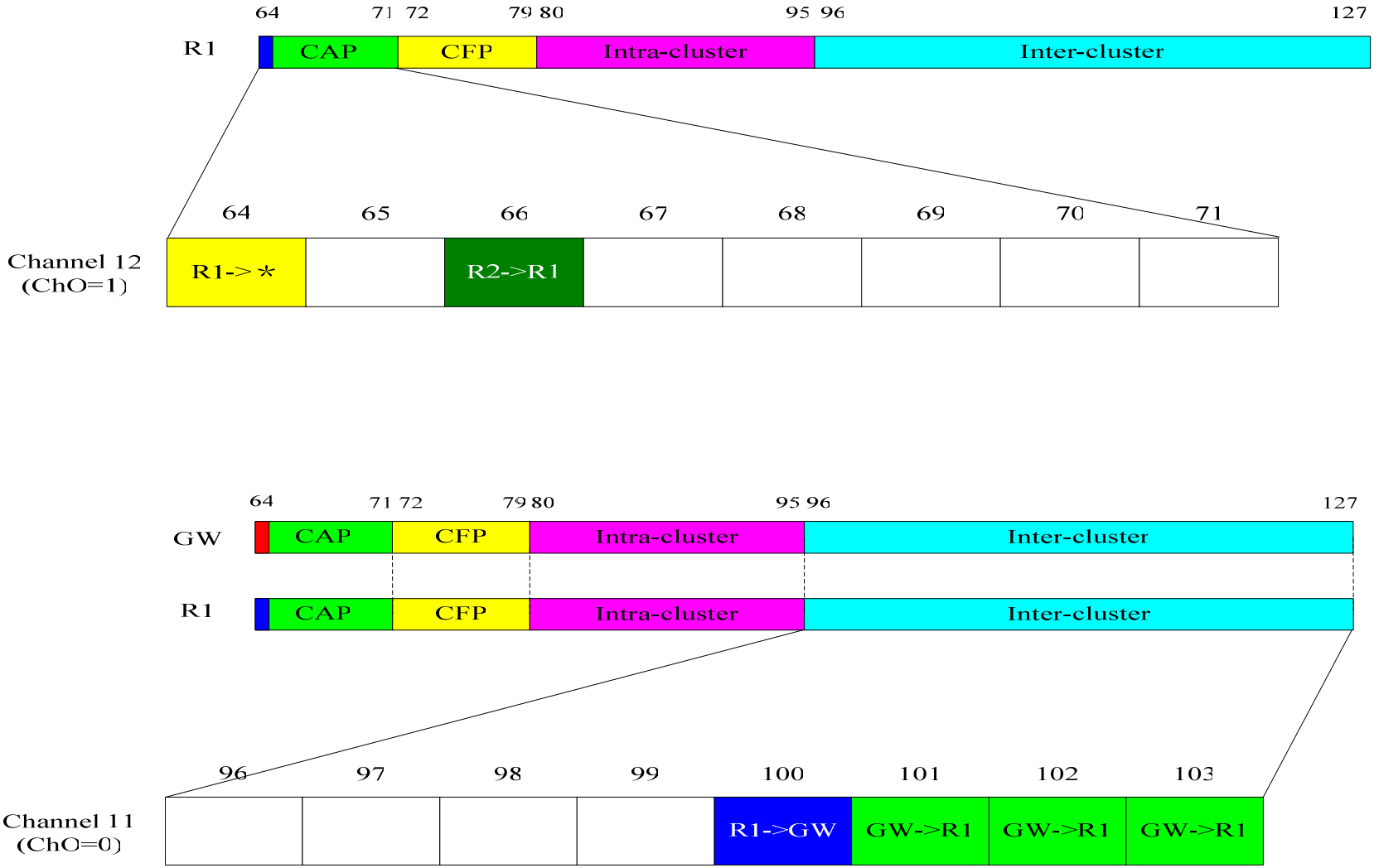
- R1 allocates resources to N1

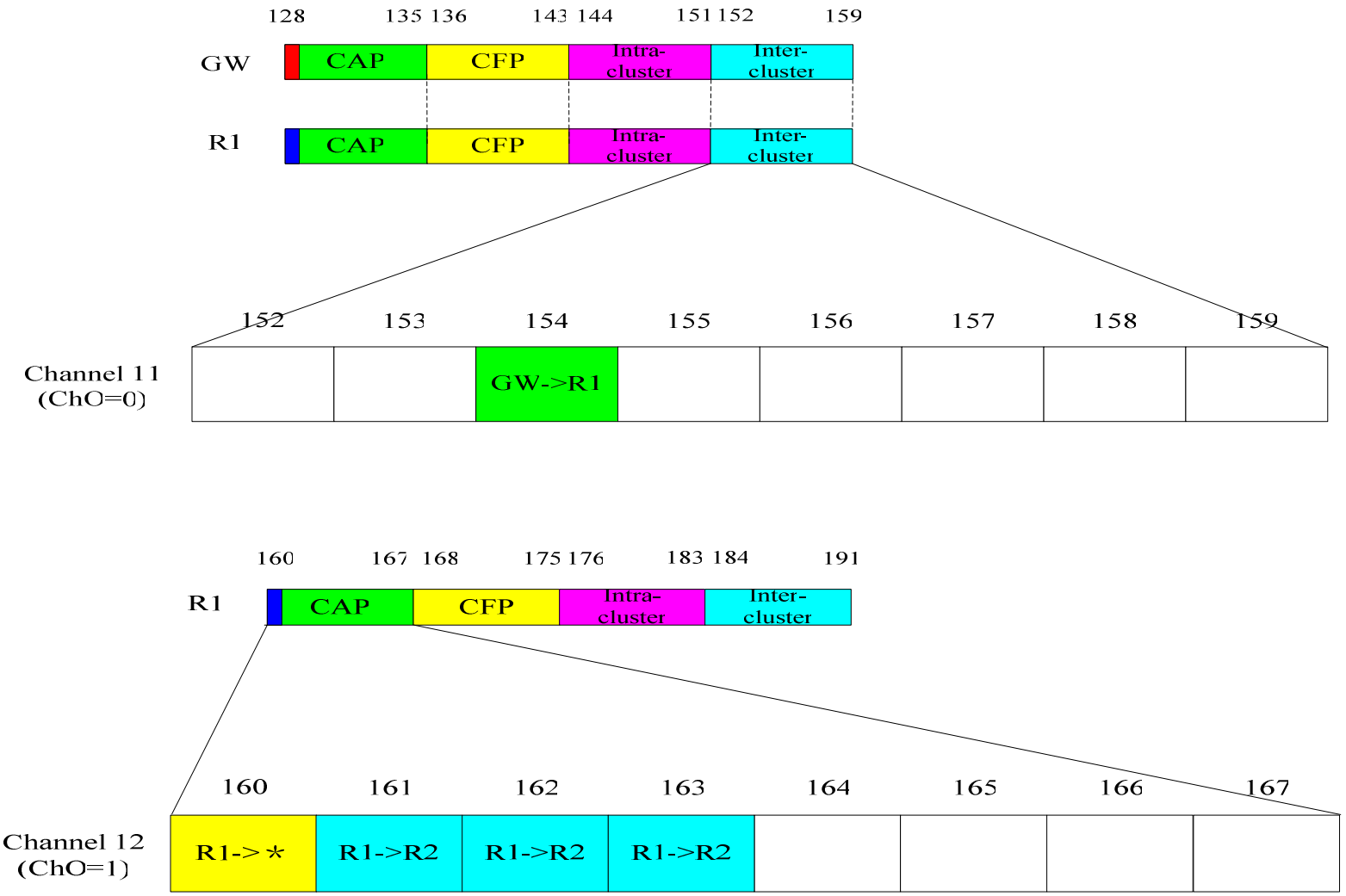


Joining and resource allocation of R2

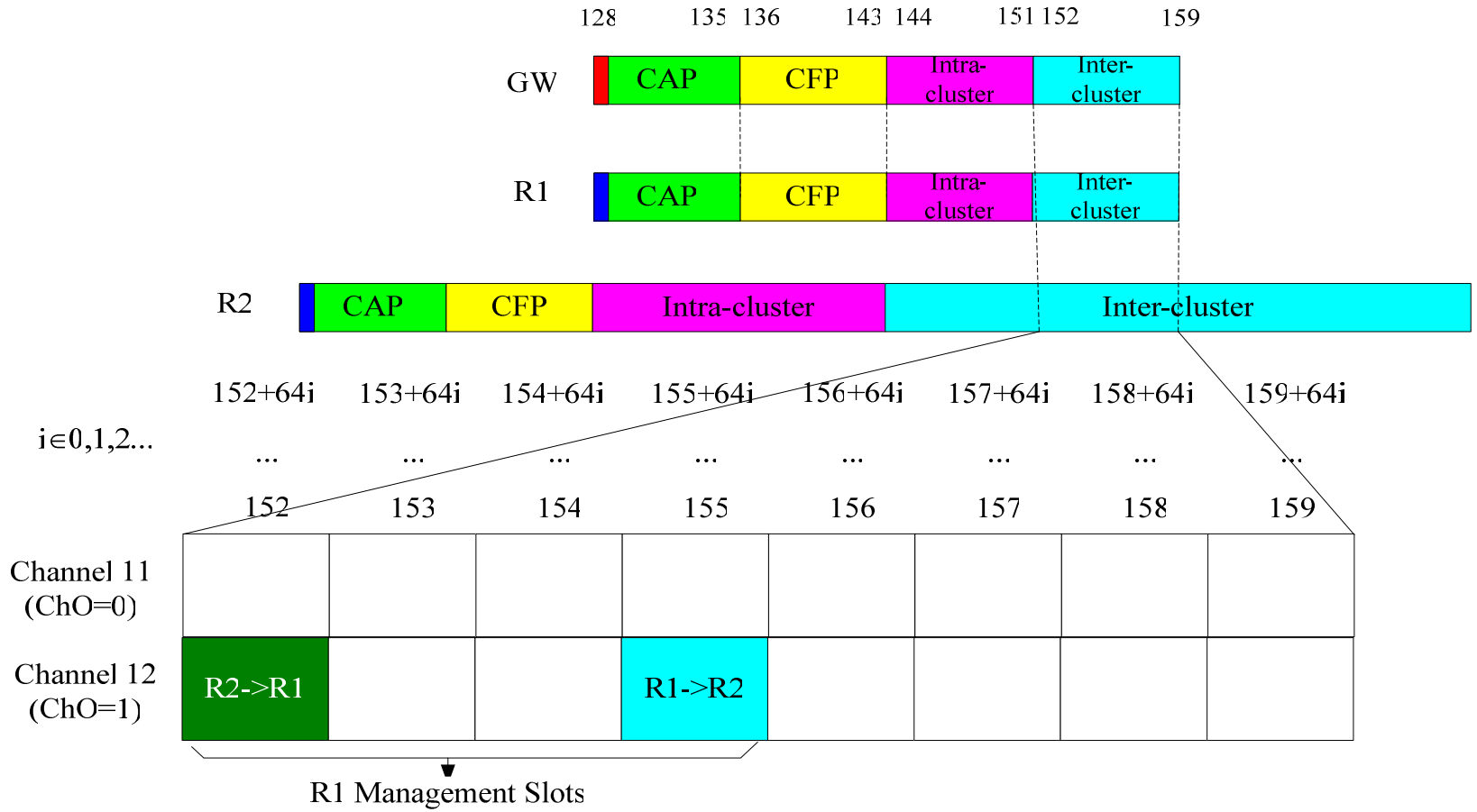




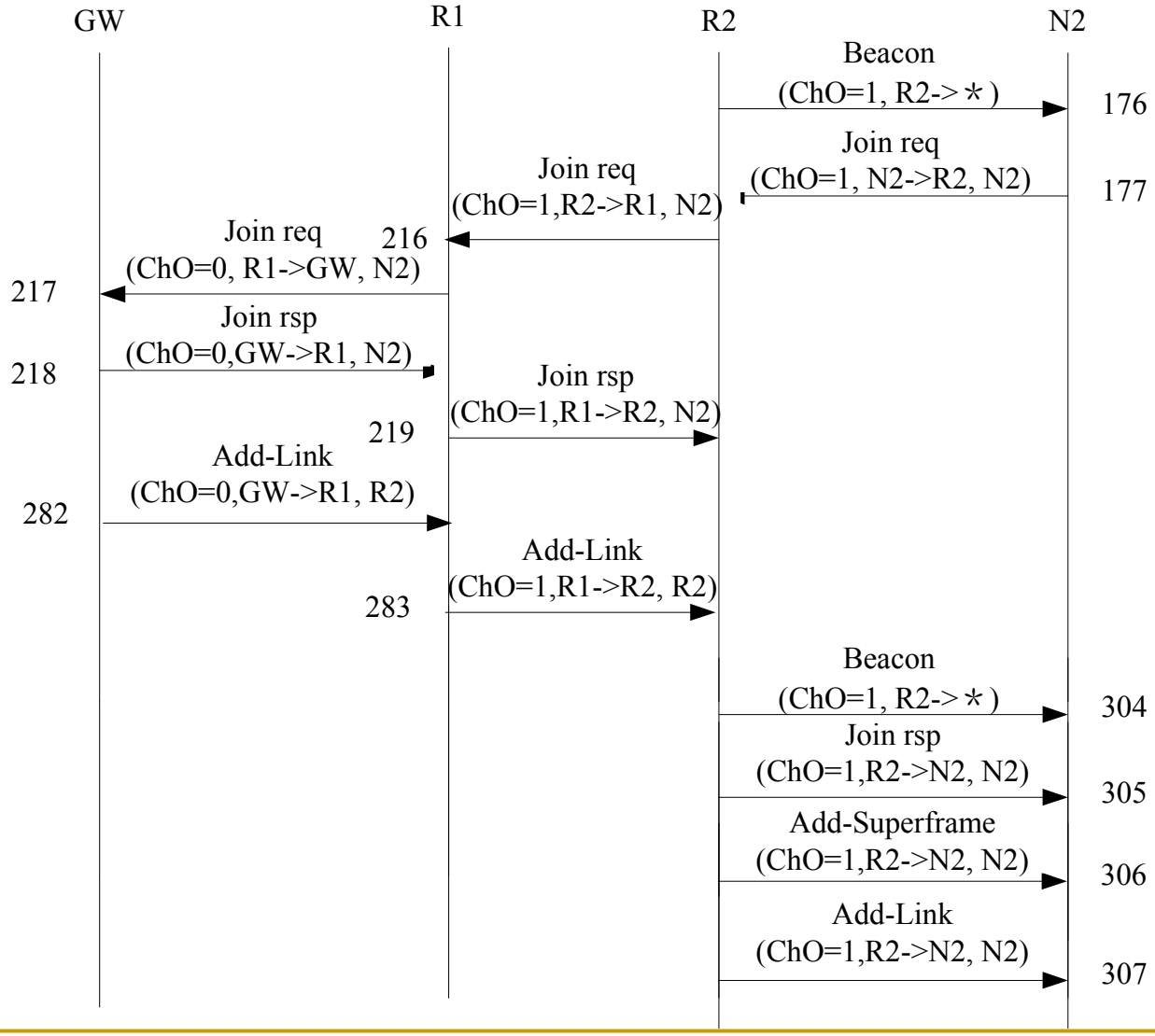

64
71 72
79 80
95 96
127
R1
CAP
CFP
Intra-cluster
Inter-cluster
64
65
66
67
68
69
70
71
Channel 12
(ChO=1)
R1-> *
R2->R1
64
71 72
79 80
95 96
127
GW
CAP
CFP
Intra-cluster
Inter-cluster
R1
CAP
CFP
Intra-cluster
Inter-cluster
96
97
98
99
100
101
102
103
Channel 11
(ChO=0)
R1->GW
GW->R1
GW->R1
GW->R1

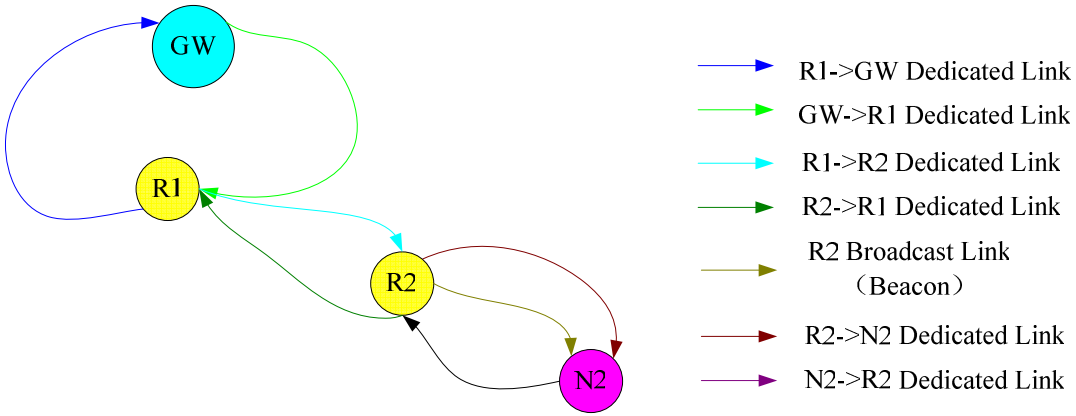

128
135 136
143 144
151 152
159
GW
CAP
CFP
Intra-cluster
Inter-cluster
R1
CAP
CFP
Intra-cluster
Inter-cluster
152
153
154
155
156
157
158
159
Channel 11
(ChO=0)
GW->R1
160
167 168
175 176
183 184
191
R1
CAP
CFP
Intra-cluster
Inter-cluster
160
161
162
163
164
165
166
167
Channel 12
(ChO=1)
R1->*
R1->R2
R1->R2
R1->R2

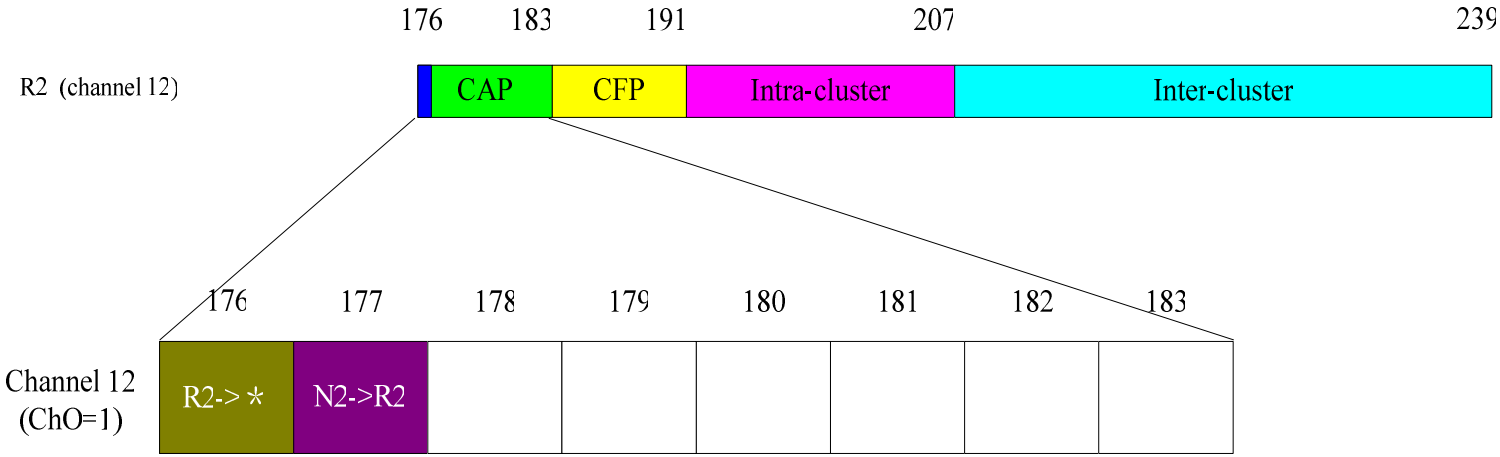
GW allocates management slots to R2

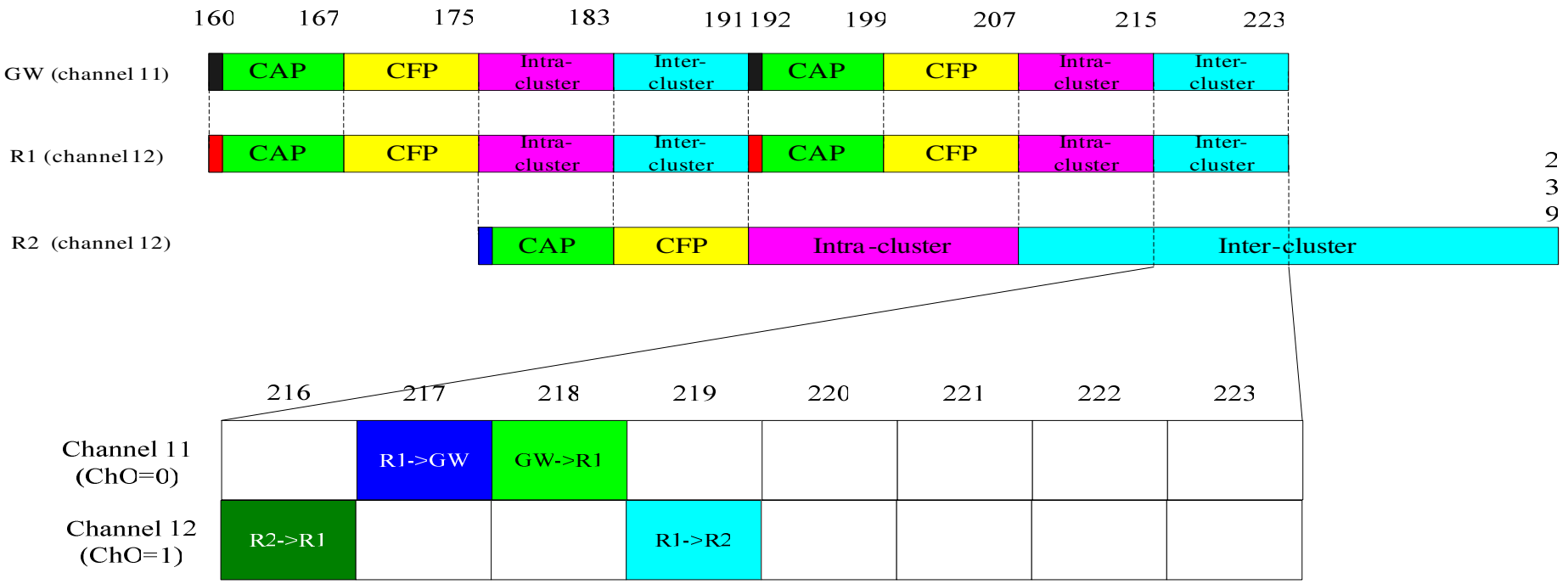


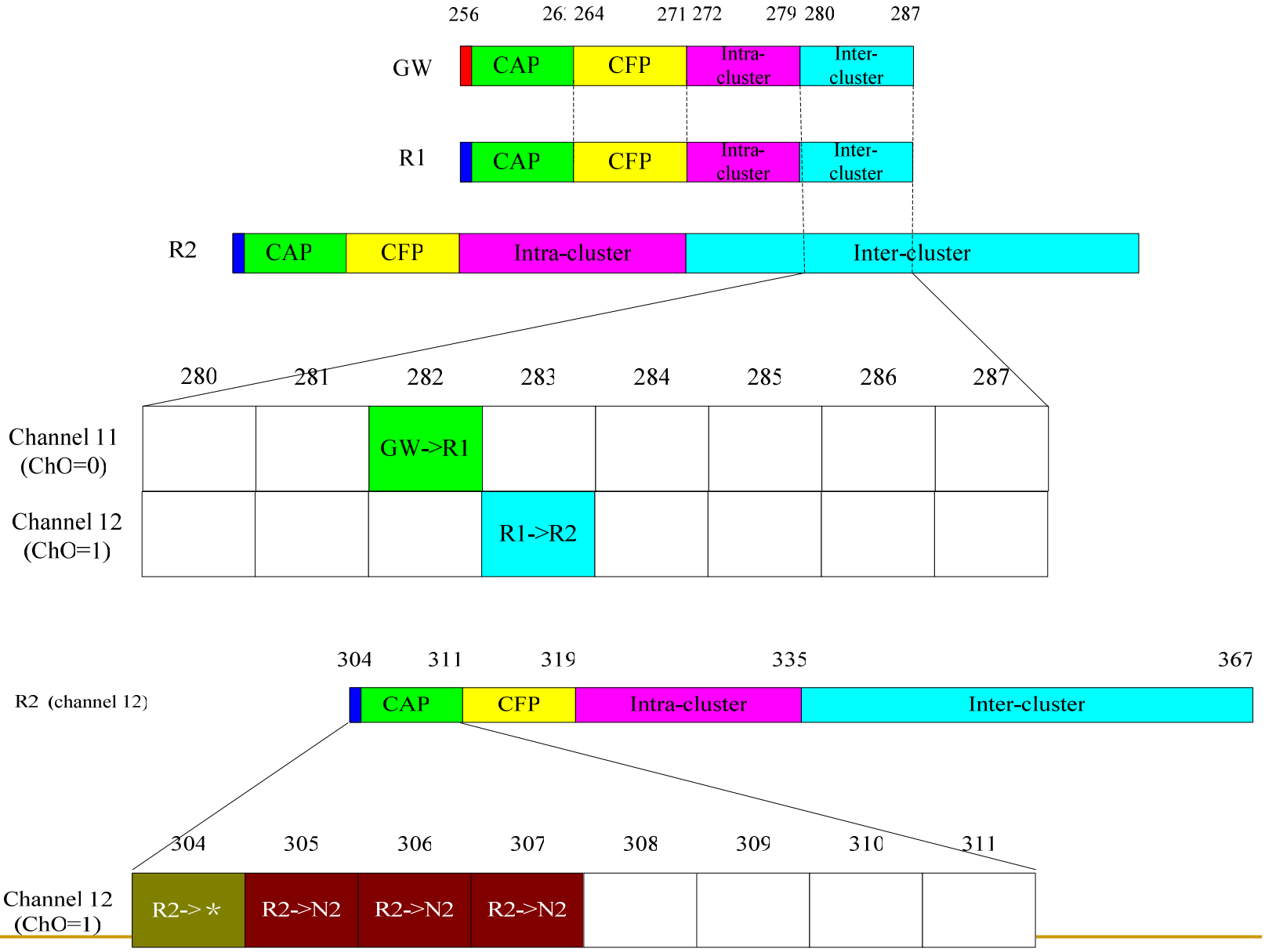
Joining and resource allocation of N2



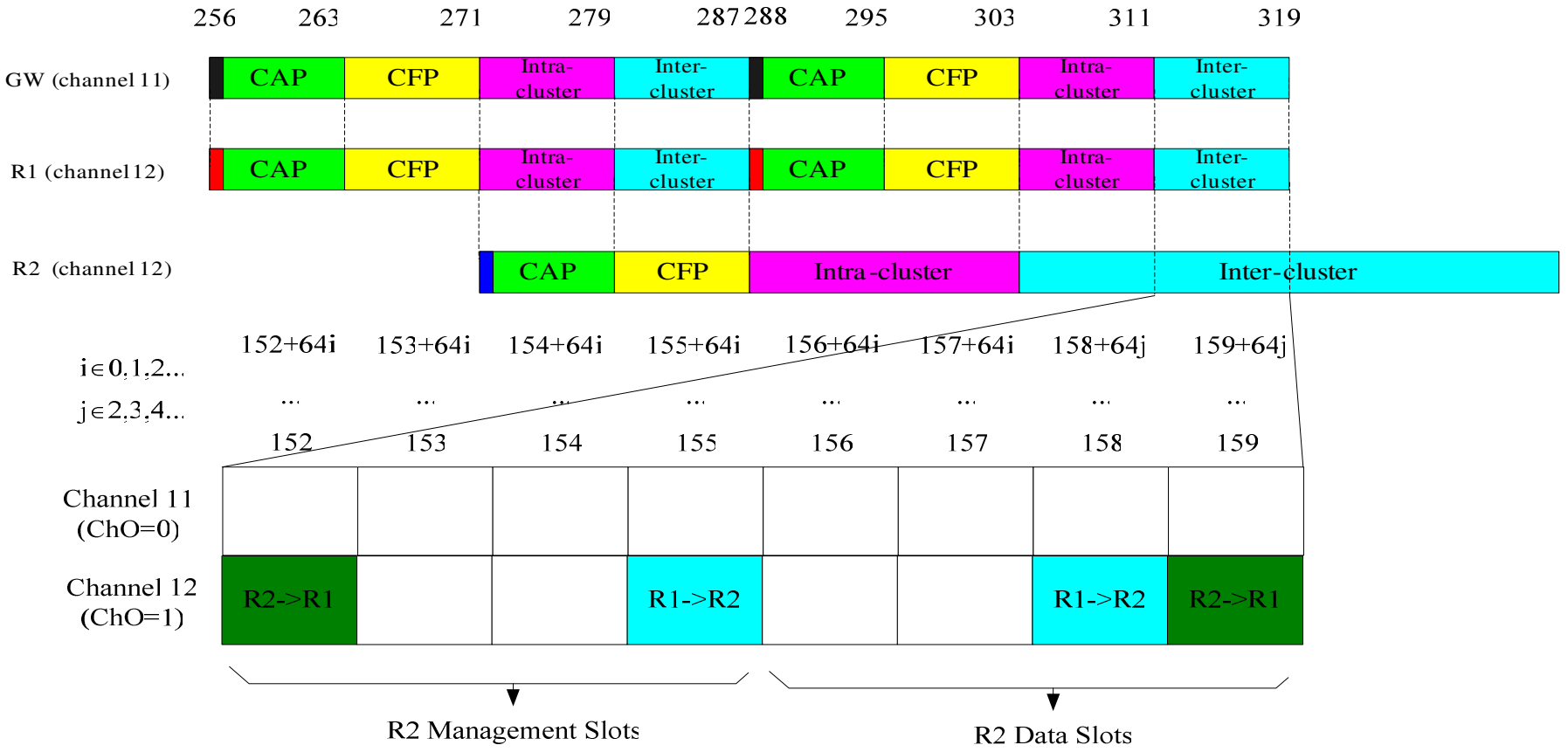

GW
R1
R2
N2
R1->GW Dedicated Link
GW->R1 Dedicated Link
R1->R2 Dedicated Link
R2->R1 Dedicated Link
R2 Broadcast Link
（Beacon）
R2->N2 Dedicated Link
N2->R2 Dedicated Link


176
183
191
207
239
R2 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
176
177
178
179
180
181
182
183
Channel 12
(ChO=1)
R2->*
N2->R2

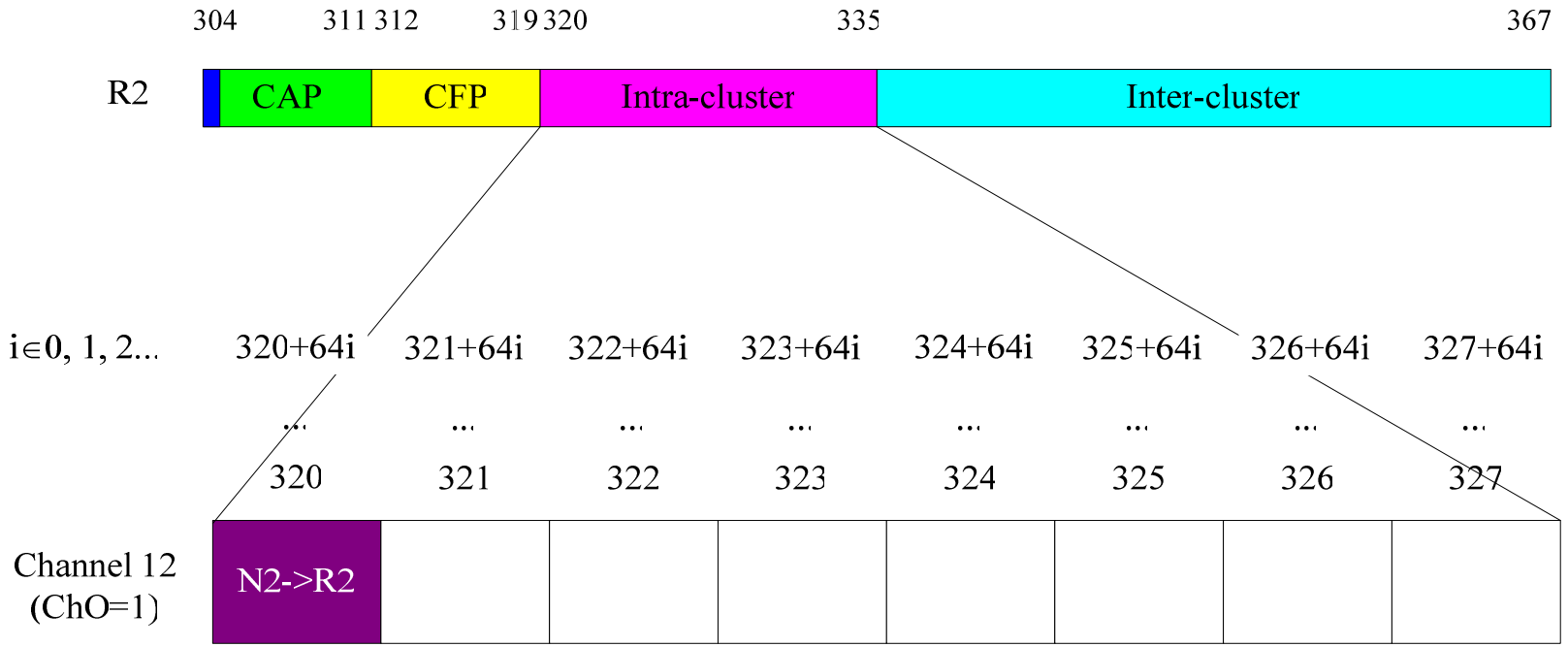

160
167
175
183
191
192
199
207
215
223
GW (channel 11)
R1 (channel 12)
R2 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
Intra-cluster
Inter-cluster
2
3
9
216
217
218
219
220
221
222
223
Channel 11 (ChO=0)
Channel 12 (ChO=1)
R1->GW
GW->R1
R2->R1
R1->R2


256
26. 264
271 272
279 280
287
GW
CAP
CFP
Intra-cluster
Inter-cluster
R1
CAP
CFP
Intra-cluster
Inter-cluster
R2
CAP
CFP
Intra-cluster
Inter-cluster
280
281
282
283
284
285
286
287
Channel 11
(ChO=0)
GW->R1
Channel 12
(ChO=1)
R1->R2
304
311
319
335
367
R2 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
304
305
306
307
308
309
310
311
Channel 12
(ChO=1)
R2->*
R2->N2
R2->N2
R2->N2

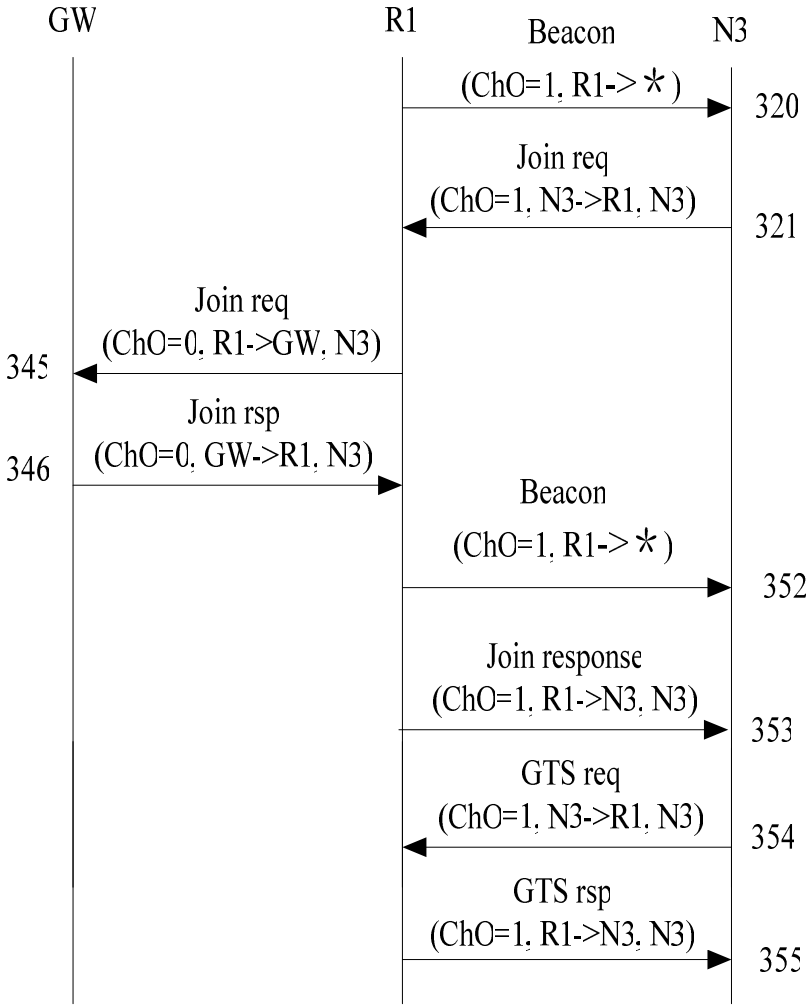
- After GW receiving N2's joining request, GW allocates data slots to R2 (see above figure for detail)

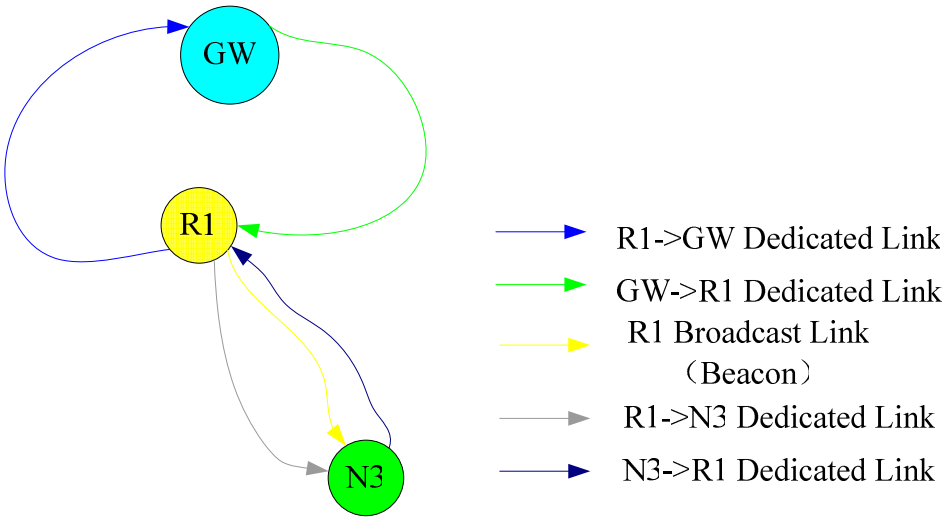


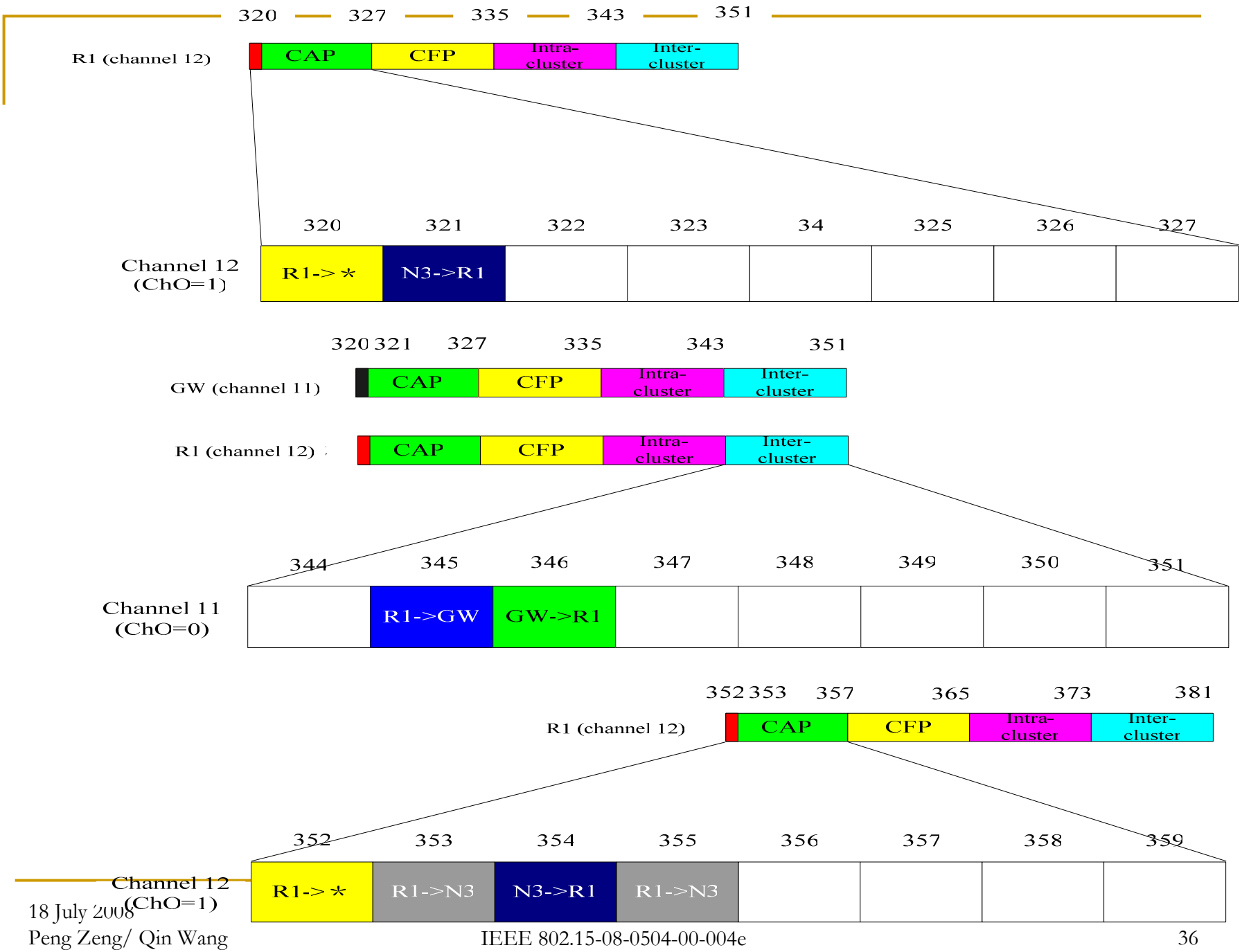
- R2 allocates resources to N2



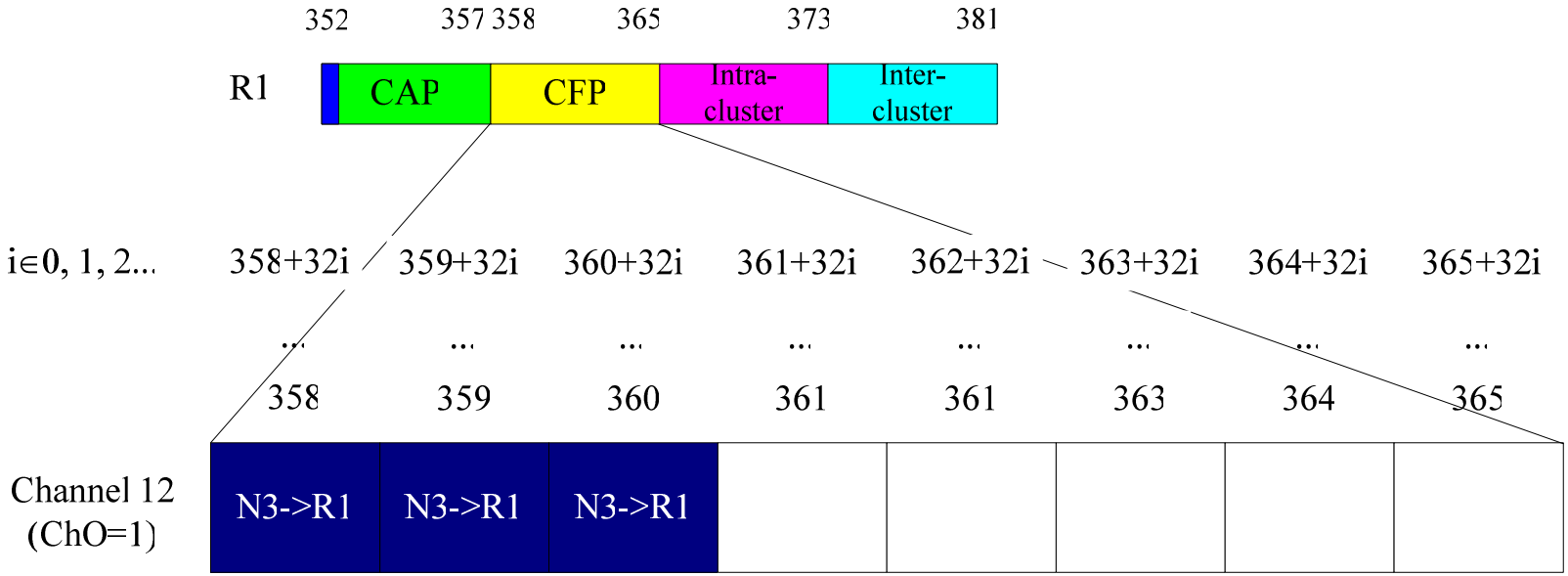
Joining and resource allocation of N3





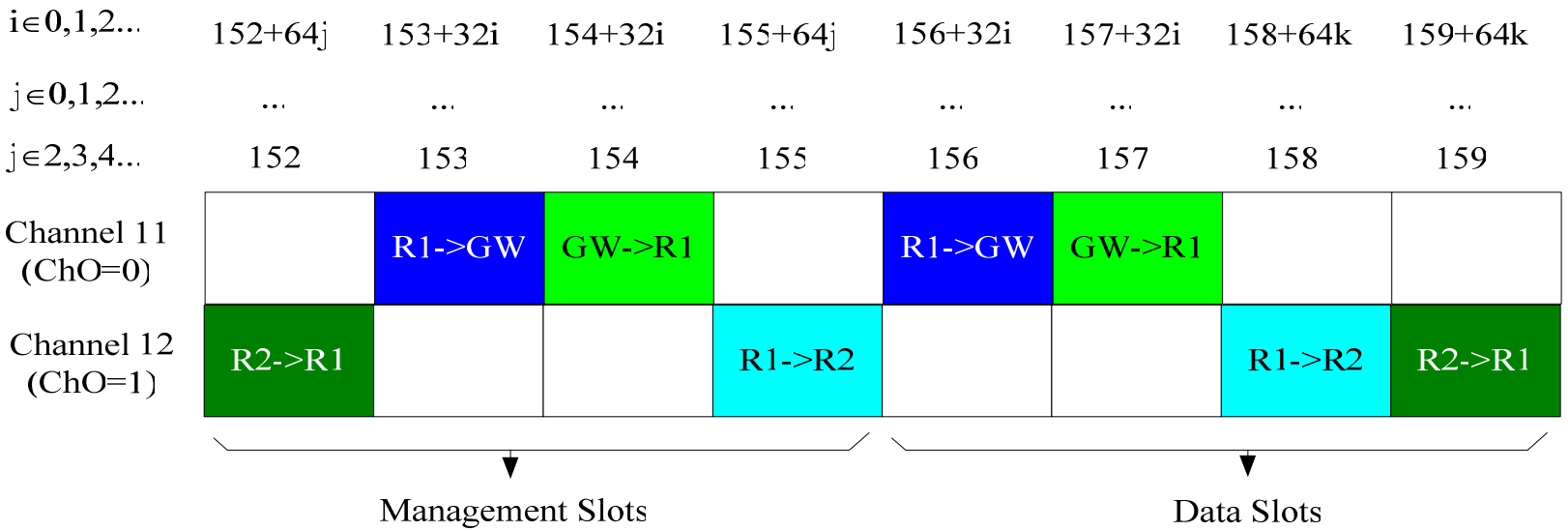

320
327
335
343
351
R1 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
320
321
322
323
34
325
326
327
Channel 12 (ChO=1)
R1-> *
N3->R1
320 321
327
335
343
351
GW (channel 11)
CAP
CFP
Intra-cluster
Inter-cluster
R1 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
344
345
346
347
348
349
350
351
Channel 11 (ChO=0)
R1->GW
GW->R1
352 353
357
365
373
381
R1 (channel 12)
CAP
CFP
Intra-cluster
Inter-cluster
352
353
354
355
356
357
358
359
Channel 12 (ChO=1)
R1-> *
R1->N3
N3->R1
R1->N3

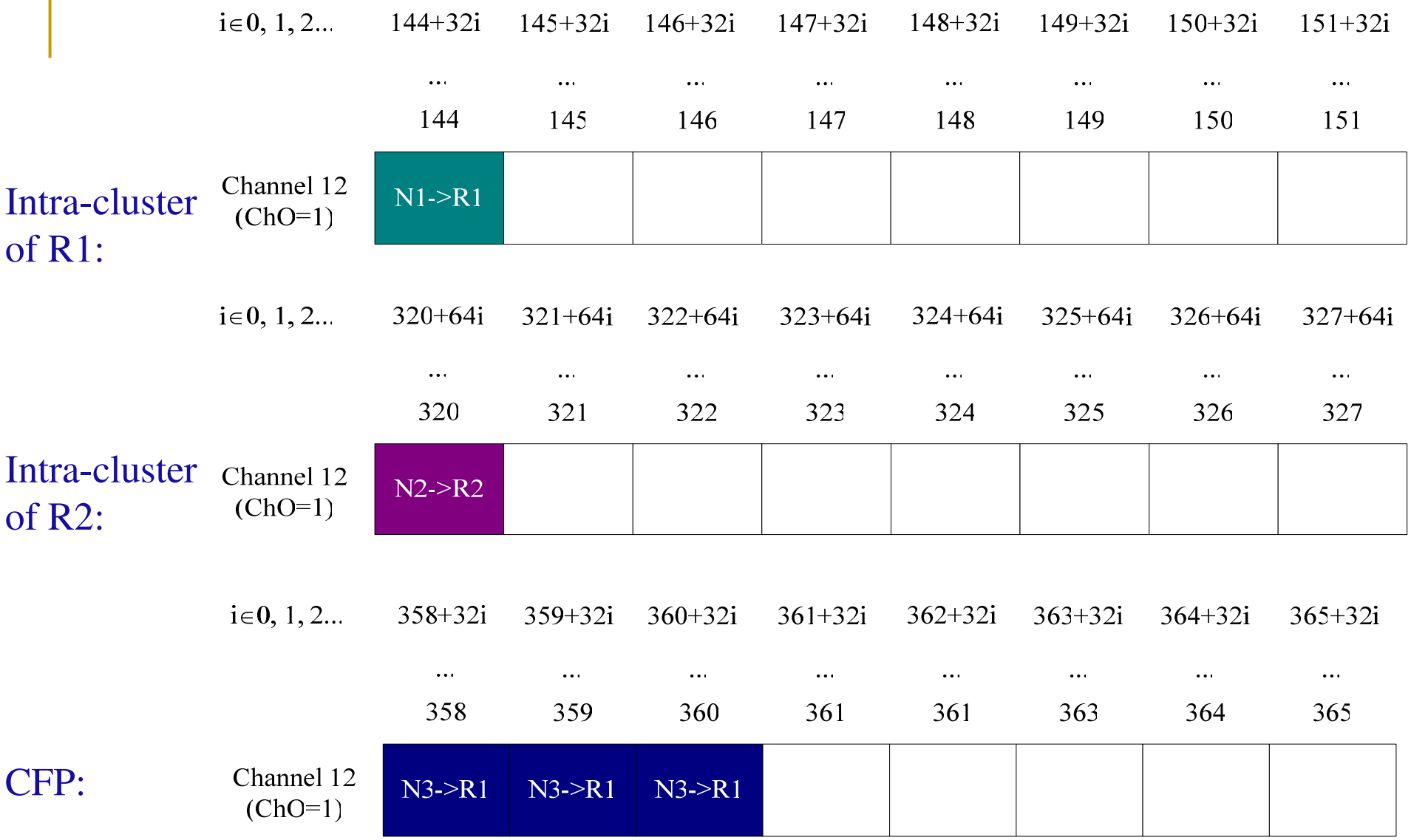
- R1 allocates resources to N3: 3 slots



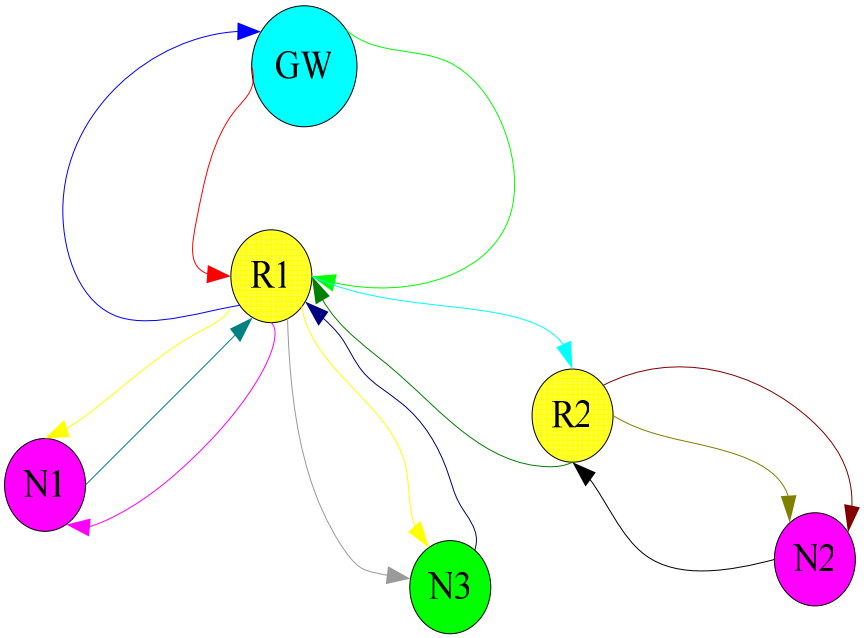
Overall Resource Allocation Graph

Inter-cluster:



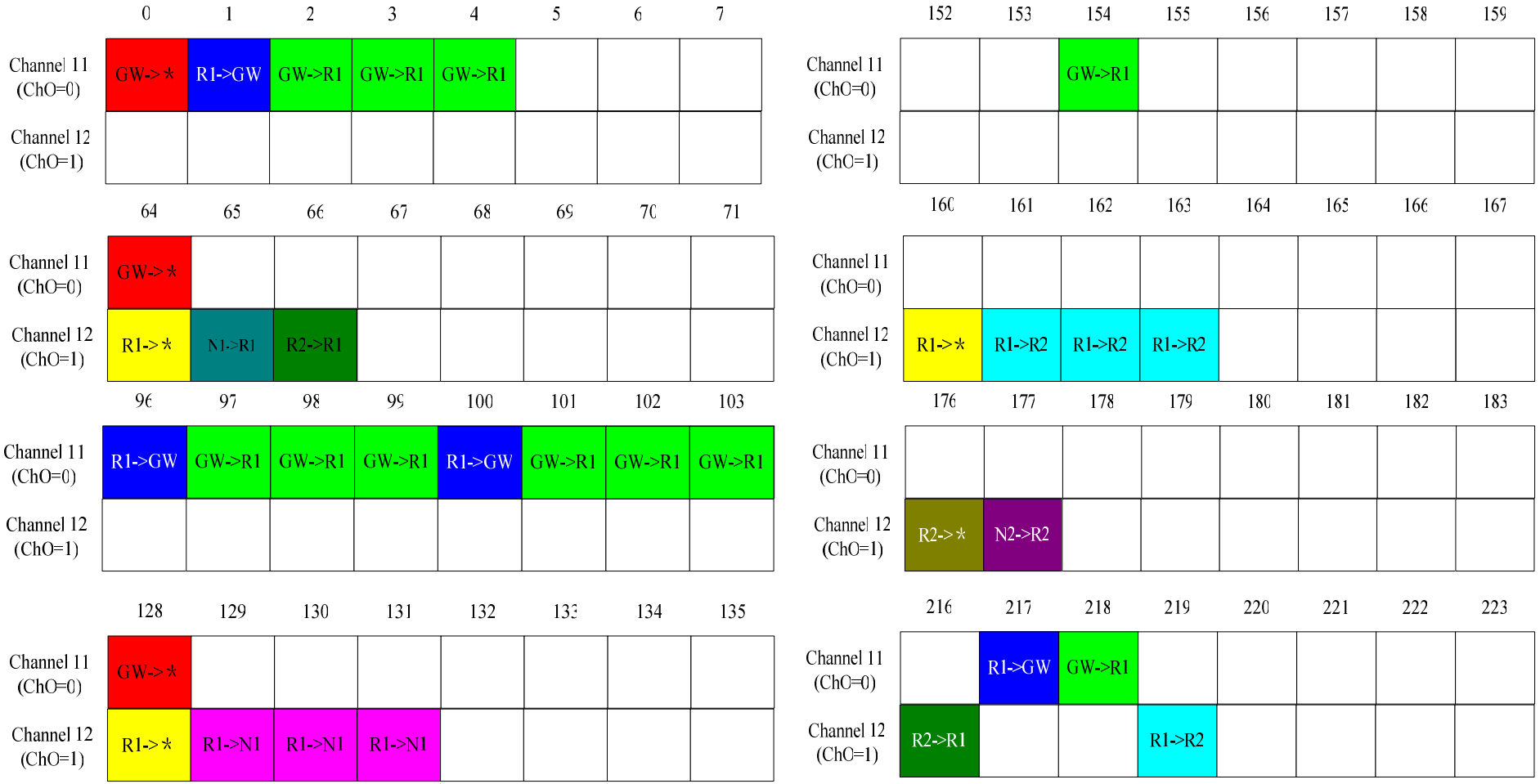

i∈0, 1, 2...
144+32i
145+32i
146+32i
147+32i
148+32i
149+32i
150+32i
151+32i
...
144
145
146
147
148
149
150
151
Intra-cluster of R1:
Channel 12 (ChO=1)
N1->R1
i∈0, 1, 2...
320+64i
321+64i
322+64i
323+64i
324+64i
325+64i
326+64i
327+64i
320
321
322
323
324
325
326
327
Intra-cluster of R2:
Channel 12 (ChO=1)
N2->R2
i∈0, 1, 2...
358+32i
359+32i
360+32i
361+32i
362+32i
363+32i
364+32i
365+32i
358
359
360
361
361
363
364
365
CFP:
Channel 12 (ChO=1)
N3->R1
N3->R1
N3->R1

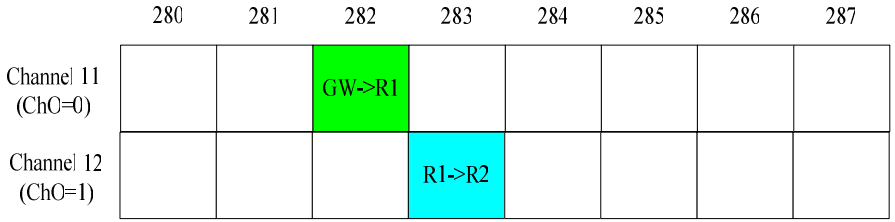
Overall Link Graph

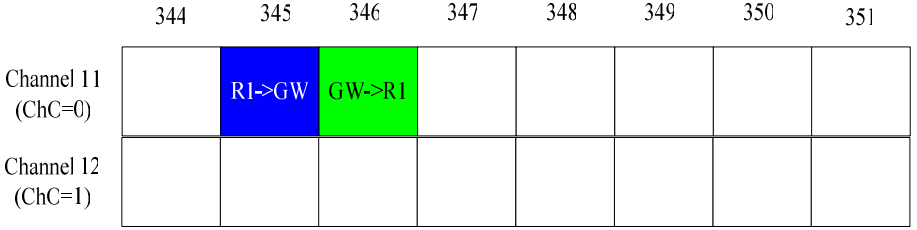


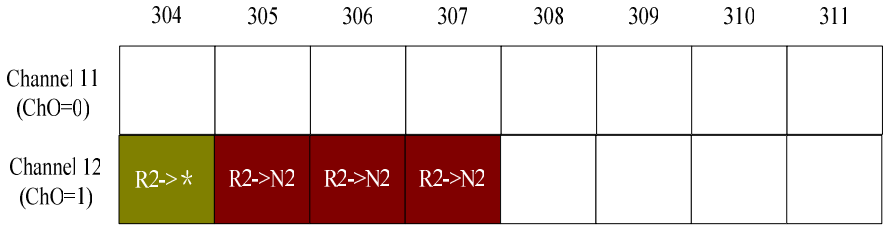
GW Broadcast Link
R1->GW Dedicated Link
GW->R1 Dedicated Link
R1 Broadcast Link
R1->R2 Dedicated Link
R2->R1 Dedicated Link
R2 Broadcast Link
R2->N2 Dedicated Link
N2->R2 Dedicated Link
R1->N3 Dedicated Link
N3->R1 Dedicated Link
R1->N1 Dedicated Link
N1->R1 Dedicated Link

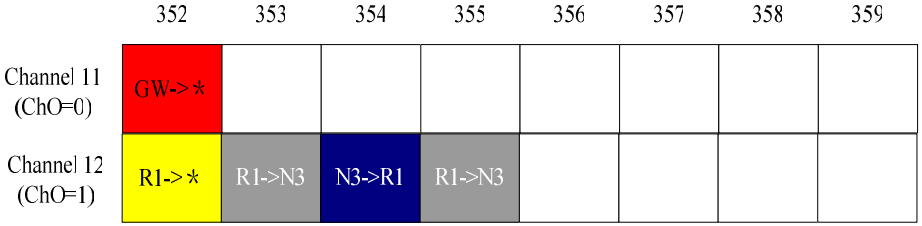
Used Resource of Device Joining Process

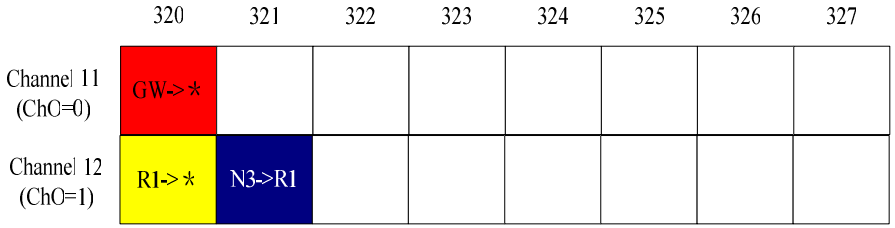



280
281
282
283
284
285
286
287
Channel 11
(ChO=0)
Channel 12
(ChO=1)
GW->R1
R1->R2


344
345
346
347
348
349
350
351
Channel 11
(ChC=0)
Channel 12
(ChC=1)
R1->GW
GW->R1


304
305
306
307
308
309
310
311
Channel 11
(ChO=0)
Channel 12
(ChO=1)
R2->*
R2->N2
R2->N2
R2->N2


352
353
354
355
356
357
358
359
Channel 11
(ChO=0)
Channel 12
(ChO=1)
GW->*
R1->*
R1->N3
N3->R1
R1->N3


320
321
322
323
324
325
326
327
Channel 11
(ChO=0)
Channel 12
(ChO=1)
GW->*
R1->*
N3->R1